Essentials of Biology and Biophysics with Medical Applications of Radiotherapy

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Contents

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Preface

Just as the 19th century can be considered the age of cellular biology, the 20th and 21st centuries were characterized primarily by developments in molecular biology.

In the 1970s the development of recombinant DNA technology opened the way to genetic engineering, which enabled researchers to recombine nucleic acids and thereby modify organisms' genetic codes, giving the organisms new abilities or eliminating undesirable traits. Those developments were followed by advances in cloning technologies, which led to the generation in 1996 of Dolly the sheep, the first clone of an adult mammal. Together, recombinant DNA technology and reproductive cloning (the method used to produce a living animal clone) facilitated great progress in the development of genetically modified organisms (GMOs). Such organisms became crucial components of biomedical research, where genetically modified (GM) mice and other animals were developed to model certain human diseases, thereby facilitating the investigation of new therapies and the factors that cause disease. Recombinant DNA technology played a crucial role in the generation of GM crops, including pest-resistant forms of cotton and herbicide-resistant forms of maize (corn) and soybeans.

Welcome to Physics

Chapter

1

Chapter One/ Physics

1-Radiation

In the physical sense, waves or particles in the form of radiation can be transmitted via space or a physical medium. This contains the following items:

• "Microwave radiation, infrared light, ultraviolet light, x-rays, and gamma radiation" are all examples of electromagnetic radiation (EMR) emissions (as well as other types of radiation).

Alpha radiation (α), beta radiation (β)

Particle radiation includes, but is not limited to, the following types of radiation: Radiation in the form of alpha rays (α), beta rays (β), proton ray, and neutron rays (The non-zero rest energy particles).

• sound and seismic waves are examples of acoustic radiation (Physical media are required to transmit data).

• gravitational radiation, radiation in the system of The curved shape of ripples space-time.

Ionizing and non-ionizing radiation can be classified by the energy of the particles that are radiated. In order for ionizing radiation to ionize and break chemical bonds, it must carry more than 10 eV, which it does. Because to their vastly differing levels of toxicity, this distinction is critical. Radioactive materials emitting helium nuclei, electrons or positrons, or photons, respectively, are a typical source of ionizing radiation. In addition, It is possible to get X-rays from medical radiography and secondary cosmic rays, which are created when primary and secondary cosmic rays collide with each other.

The ionizing part of the EM spectrum is comprised of gamma rays, X-rays, and ultraviolet light with advanced energy levels. The term "ionize" raises to the separation of one or more electrons from an atom, which is accomplished by the use of the comparatively high energy provided by electromagnetic waves. Non-ionizing lower ultraviolet spectrum energy can't ionize atoms as you move down the spectrum. but they can disturb the inter-atomic bonds that hold molecules together, resulting in

molecules being broken down quite than individual atoms, Sunburn caused by long-wavelength solar UV is a good illustration of this. Visual light, infrared light, and microwave frequencies have a longer wavelength than ultraviolet (UV), but they can source vibrations in bonds that are experienced as heat. Waves with a longer wavelength than UV in visible light, infrared light, and microwave frequencies are unable to break down bonds. Biological systems are generally not thought to be harmed by radiofrequency wavelengths and lower. When it comes to the impacts of different frequencies, there is considerable overlap between them. therefore, they are not clear delineations of the energies.

From a source, waves radiate (i.e., travel outward in all directions) and are known as radiation. This means to a universal set of measures and physical units that may be used for all forms of radiation. Radiation from a point source expands for example it travels through space, In a vacuum, the source's energy is preserved, but all radiation emitted by it tails an inverse-square rule in terms of distance from the source. Using the inverse-square law, a measured radiation intensity can be approximated as close to a geometric point as possible, like any other ideal law.

Sources and levels of radiation in the environment

Natural sources

The evolution of life has occurred in the presence of natural background ionizing radiation from the beginning of time, the primary types and sources of radioactive radiation, which are as follows: (1) cosmic rays, which come from outer space and strike the Earth; (2) terrestrial radiation, radium-40, thorium-14 and other radioactive minerals in the Earth's crust are released, as are internal radiations (potassium-40, carbon-14, This gas is being free by the disintegration of uranium and other radioactive materials in the Earth's crust.). then other radioactive isotope. An individual residing at sea level receives an average total dose of about 0.91 mSv per year from all three sources, according to Table 6; however, a dose twice this size may be received by an individual residing at a higher elevation, such as Denver, Colo. a person who lives in a place where the radium content of the soil is relatively high. Inhalation of the radon and its decomposition products can result in a yearly dose of up to 100 mSv in the lungs of the occupants of such a building. The radioactive gas radon, which is formed during the decay of radium, may enter a residence through its floor or basement walls and accumulate in the indoor air unless the dwelling is thoroughly aired on a regular basis in this type of environment.

Estimates of average annual dose equivalent to the whole body from various sources of irradiation received by members of the U.S. population	
source of radiation	average dose rates (mSv/year)
Natural	
environmental	
cosmic radiation	0.27 (0.27–1.30)*
terrestrial radiation	0.28 (0.30–1.15)**
internal radioactive isotopes	0.36
subtotal	**0.91**
Man-made	
environmental	
technologically enhanced	0.04
global fallout	0.04
nuclear power	0.002
medical	
diagnostic	0.78
radiopharmaceuticals	0.14
occupational	0.01
miscellaneous	0.05
subtotal	**1.06**
total	**1.97**

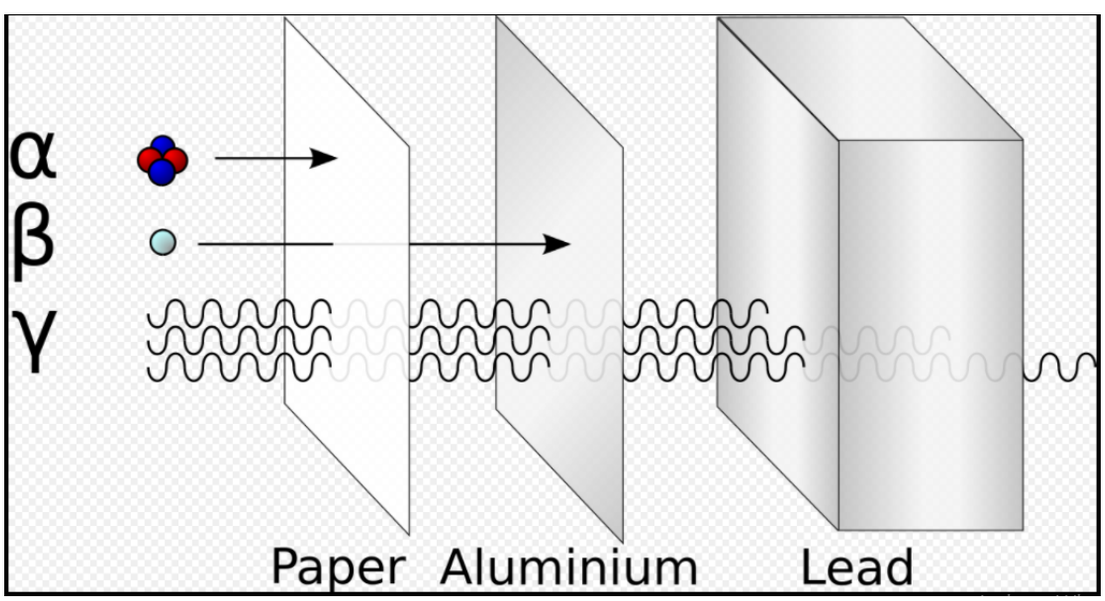
* For each state, the values in parenthesis illustrate how the average levels fluctuate as elevation increases.

** The range of fluctuation displayed in parentheses is mostly due to variations in the Earth's crust's potassium-40, radium, thorium, and uranium concentration.

Typical doses to exposed tissue received in routine X-ray diagnosis

examination	dose per exposure in milligray (mGy)*
X-ray photograph	
chest	0.4–10
abdominal	10
extremities	2.5–10
fluoroscopy	100–200 per minute
X-ray movies	250 per examination
CAT scan	50–100 per examination

*Milligray is a unit of absorbed radiation dose; it corresponds to 1/1,000 joule of radiation energy absorbed per kilogram of tissue.



What is radiation?

Radiation is a source of energy. As energy waves or high-speed particles, it moves. Radiation can be natural or man-made. Types include:

Non-ionizing radiation, which includes radio waves, cell phones, microwaves, infrared radiation and visible light

Ionizing radiation, which includes ultraviolet radiation, radon, x-rays and gamma rays

What are the sources of radiation exposure?

There is a constant supply of radiation in the air around us. Minerals are the primary source of most of it. In the ground, soil, water, and even our bodies are radioactive materials. The sun and outer space can also be sources of background radiation. X-rays, radiation therapy for cancer, and electrical power lines are examples of man-made sources.

The chemistry of radiation

As soon as a target is bombarded by a high-energy heavy positive ion, such as the hydrogen ion H+ or the deuterium ion D+ produced by a particle accelerator or the alpha particle $4He^{2+}$ produced by nuclear decay, High-energy electrons have quite distinct starting impacts than a low-energy electron does. This is due to the fact that a particle of greater mass (m) moves at a lower velocity (v) for the equal kinetic energy ($1/2m\ v^2$) as a particle of equal or lower mass (m). A particle with a specific charge traveling at high (but not ultra-relativistic) speeds has a greater chance of interacting with the medium it is traveling through if its velocity is smaller than that of the medium. The greater the linear energy transfer between the particle and the medium is smaller This results in positively charged particles in a condensed medium such as water producing their initial effects close together in the ionization track (perhaps one or two angstroms, or one or two 10^{-8} centimeter, apart), whereas equally energetic electrons traveling through the same medium deposit energy in small collections known as spurs that may be 1,000 angstroms (10^{-5} centimeter) or more apart. Comparing the appearance of the excitation and ionization track (in the case of positive-ion bombardment) with the appearance of isolated beads on a string has been done to demonstrate the effectiveness of this technique (in the case of electron bombardment), and a comparison has also been made between the appearance of the two types of tracks. Chemical reactions (i.e. track effects) may occur depending on the density and isolation of ions, excited molecules, and electrons in the track.) that occur are drastically different from one another.

In contrast to alpha particles, beta particles, X-rays, and gamma rays have no influence on the production of hydrogen and hydrogen peroxide (H_2O_2) when water is

irradiated with them. An example of a reaction sequence that has been proposed as part of the overall considerations of water's radiation chemistry is

$H_2O \rightarrow$H + OH (1)

$2H \rightarrow H_2$ (2)

$2OH \rightarrow H_2O_2$;*i.e.,* $HOOH$ (3)

Reply (1) illustrates the early chemical implications of both ionization and excitation when they occur at the same time when ionization and excitation occur simultaneously. As previously indicated, reactions (2) and (3) are thought to occur with a high probability in dense tracks (such as those generated by alpha particles), but similar reactions are thought to occur with a low chance in isolated spurs (such as those formed by fast particles). As a result, according to the American chemist A. Oliver Allen, the hydrogen atoms and OH radicals engage in back-reaction chains with any H_2 + H_2O_2 that has previously been generated and is present in the liquid's body with a somewhat higher likelihood than usual:

$H + HOOH \rightarrow H_2O + OH$ (4)

$OH + H_2 \rightarrow H_2O + H.$ (5)

The (H)atom generated in reaction (5) then enters reaction (4), resulting in the consumption of whatever minute amounts of (H2) and (H_2O_2) are really formed in reactions (2) and (3), which are essentially undetectable no matter how long the process is run.

What are the effects of radiation exposure on one's health?

Throughout human history, radiation has been present. The low levels we're exposed to on a daily basis are what our bodies are built to handle. However, overexposure to radiation can cause tissue damage by altering cell structure and causing DNA damage. Serious health consequences, such as cancer, may result.

There are a number of factors that influence the extent of radiation-induced damage, including

The type of radiation

The dose (amount) of radiation

How you were exposed, such as through skin contact, swallowing or breathing it in, or having rays pass through your body.

Where the radiation concentrates in the body and how long it stays there.

How sensitive your body is to radiation. A fetus is most vulnerable to the effects of radiation. Infants, children, older adults, pregnant women, and people with compromised immune systems are more vulnerable to health effects than healthy adults.

Burns to the skin can occur when a large amount of radiation is applied quickly, as would be the case in a radiation emergency. Acute radiation syndrome can also result (ARS, or "radiation sickness"). Headaches and diarrhoea are two of the most common symptoms of ARS. Usually within a few hours, they begin. Some of the symptoms will go away for some time, and the person will appear to be in good health. But they'll get sick again. There is a direct correlation between the amount of radiation a patient receives and how quickly they become ill again. Death can occur within days or weeks as a result of ARS in rare circumstances.

Health risks associated with exposure to low amounts of radiation in the environment are not immediately apparent. However, it may raise your total cancer risk by a small amount.

What are the treatments for acute radiation sickness?

Your body's radiation absorption must be quantified before treatment can begin. Your symptoms, blood tests, and maybe a radiation detector will all be asked of you by the doctors. Aside from that, they try to learn more about your radiation exposure, such as what kind of radiation it was, how far away you were from the source, and how long you were exposed.

Treatment aims to reduce and treat infections, avoid dehydration, and repair injuries and burns. To aid those who have lost their bone marrow function, there are various treatments available. In the event that you have been exposed to specific forms of radiation, your healthcare professional may administer a therapy to restrict or remove the contamination from your system. You may also get treatments for your symptoms.

How can radiation exposure be prevented?

There are steps you can take to prevent or reduce radiation exposure:

Make sure to ask questions about the dangers and benefits of a radiation-based test if it's recommended by your doctor. You may be able to get a non-radiation test in some instances. However, if a radiation-based test is required, you should look into the local imaging facilities for more information. Find one that monitors and uses techniques to reduce the doses they are giving patients.

Reducing your cell phone's Electromagnetic radiation exposure is a good idea. Currently, there is no evidence that cell phone use is associated with any health issues in humans. To be sure, further investigation is needed. But if you're still concerned, you can limit the amount of time you spend on your phone. Additionally, you can use a headset or speaker mode to keep your head from being directly in front of the cell phone.

Radon levels should be checked in your home, and you should install a radon mitigation system if necessary.

Take shelter inside a structure in the event of a radiation emergency. All windows and doors should be closed inside your home during this time. The advice of rescue workers and officials should be heeded.

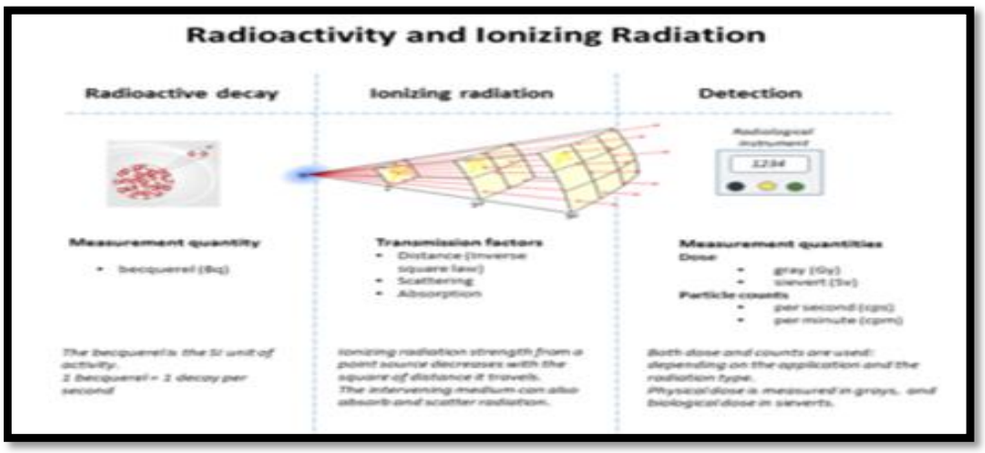
radiation that is harmful to unprotected human beings has been designated with the international mark. Various forms of radiation, such as light and sound, can be found throughout the natural world.

Ionizing Radiation

Atoms can be ionized by high-energy radiation, which removes electrons from the atoms and creates ions. A net positive charge when an electron is removed from an atom's electron shell (or "knocked out"), leaving the atom by a net negative charge. Because it damages live cells and, more importantly, the DNA within those cells, exposure to ionizing radiation is thought to increase the risk of cancer. For the sole reason of their significant potential for causing biological damage, particle and electromagnetic radiation are artificially isolated from "ionizing radiation." The fact that a single cell contains billions of atoms does not mean that just a small percentage of those atoms is susceptible to ionization by radiation with low to moderate power levels, as previously stated. The risk that ionizing radiation may cause cancer is proportional to the amount of radiation received, and it is determined by the radiation's destructive potential (equivalent dose) as well as the compassion of the irradiated tissue or organism to the radiation (effective dose).

When ionizing radiation comes from a radioactive material or a nuclear process like fission or fusion, particle radiation is an issue to consider. Subatomic particles are used to accelerate particle radiation to relativistic speeds through the use of radioactive elements and other nuclear reactions. Because the majority of them carry an electrical charge, they do not have the penetrating force of ionizing radiation, hence they are less dangerous, but their momenta make them capable of ionizing and knocking out electrons Nuclear particles are an exception to this rule. Alpha, beta, neutron, and proton are the most common types of these subatomic particles, while there are many others. When ionizing photons and particles are produced, their energies exceed around 10 electron volts (eV) (some authorities use 33 eV, the ionization energy for water). Particle radiation from radioactive materials or cosmic rays is almost always ionizing, whether it comes from radioactive materials or cosmic rays.

ionizing radiation is mostly created by cosmic rays and radioactive elements, therefore it is ubiquitous in the natural world, where it can be found in minute amounts in most rocks and soil. A Geiger counter is frequently necessary because this radiation is invisible and cannot be detected by human senses. When it comes into contact with matter, it can produce secondary emission of visible light, Cherenkov radiation, for example. and radioluminescence.



Radioactivity and ionizing radiation correlations

Even though ionizing radiation takes numerous useful applications in the fields of medicine, research, and construction, it can be harmful to human health if not utilized correctly. Biological effects of radiation include cancer and genetic damage, and thyroid cancer is a common cancer associated with nuclear weapons and reactors Radiation-induced acute radiation syndrome (ARS) is a serious kind of radiation poisoning that can result in severe burns, hair loss, organ failure, and even death at high doses of radioactive iodine fission product iodine-131. Ionizing radiation-induced cancer formation in cells is still poorly understood, and current estimates are based on population-based data from Hiroshima and Nagasaki bombs and follow-up investigations into reactor mishaps like the Chernobyl tragedy. There are many uncertainties and inaccuracies in the models and parameter values used, according to the International Commission on Radiological Protection. As the Commission points out, "collective effective dosage is not intended to be used as a tool for epidemiological risk assessment and should not be used for projecting risk." It is particularly important to prevent the estimate of the number of cancer deaths based on aggregate effective doses from inconsequential individual doses.

Units that measure ionizing radiation

The ionizing radiation can be measured in a variety of ways. The roentgen (R) is the oldest unit and represents the quantity of radiation needed to produce one electrostatic part of charge in one cubic centimeter of air under ordinary pressure circumstances. temperature and relative humidity are two important factors to consider. Radiation dose is usually expressed in gray (Gy: 1 Gy = 1 joule of radiation energy per kilogram of tissue), however, the rad (100 ergs per gram of tissue = 0.01 Gy) is the unit most commonly used to express it in living tissue. Radiation doses can be normalized in terms of RBE (relative biological effectiveness) using the sievert (Sv) and the rem, as particle radiations tend to inflict more damage for the same amount of radiation than do X-rays then gamma rays. If the RBE of the radiation is known, then the dose equivalent (in Sv) of that radiation is just the dosage in Gy increased by the quality factor. One sievert is roughly similar to one dull of gamma rays (1 Sv = 100 rem) in terms of biological efficiency. It is common practice to use milligrays and millisieverts in place of sieverts and rems since they are smaller and more practical for some purposes.

Units such as being-Sv and person-rem are commonly used to describe the total dose given to a group of people. These units are the average quantity per person times the number of people exposed (e.g., 1 Sv to each of 100 people = 100 person -Sv = 10,000 person-rem).

Units for determining the amount of radioactivity in a specific sample of materials include Bq and CUrie (Ci). A becquerel is equal to one atomic disintegration per second, while a curie is equal to 3.7×10^{10} atomic disintegrations per second (1 Bq = 2.7×10^{-11} Ci) of a radioactive element. Dose commitment refers to the amount of

radiation that will accumulate over a particular length of time (say, 50 years) following exposure to a given source of radiation.

UV (Ultraviolet) radiation

Ozone (O3) is a powerful absorber of ultraviolet radiation with a wavelength range of 10 nm–125 nm, which causes it to be strongly absorbed by the air. Because ionizing UV does not penetrate Earth's atmosphere to a significant extent, it is sometimes referred to as vacuum ultraviolet. However, even though it is present in space, it has no biological significance because it does not reach living organisms here on Earth.

An area of the atmosphere in which ozone predominates absorbs nearly all of the potentially harmful UV-C and UV-B radiation. There is a so-called ozone layer that begins at about 20 miles (32 kilometers) above the ground and extends upwards into the atmosphere. Because single photons of this frequency can produce electrical excitation in biological molecules and harm them as a result of undesired reactions, even when UV radiation does not reach the ground, it is still biologically harmful. An case is the production of DNA pyrimidine dimers, which begins at a wavelength of 365 nm (3.4 eV), which is so low that it isn't even close to being visible. UV rays are therefore associated with some of the risks of ionizing radiation in biological systems, without actually producing ionization in the process. Photons in visible light and longer-wavelength electromagnetic radiation (e.g. microwaves and radio waves) have insufficient energy to cause detrimental molecular excitation, and as a result, this radiation is significantly less dangerous per unit of energy than other types of electromagnetic radiation.

X-rays

These are called x-rays because they have a wavelength of less than or equal to the length of 10^9 meters (greater than $3x10^{17}$ Hz and 1,240 eV). According to $E=h\ c/\lambda$, a higher energy is associated with a shorter wavelength. Planck's constant, the speed of light, and the wavelength (λ)are all represented by the letters "E" and "h," respectively. You may see the electron go up an orbit, or you may see the electron be knocked out of the atom entirely, depending on the X-ray photon's energy level and how much of an impact the photon has. X-ray photons are more readily absorbed by atoms having a greater difference in electron orbital energy, as is the case in most

materials. Radiation is taken up by bone differently than that which is found in soft tissue because the atom sizes are smaller in bone. Radiation from X-ray machines allows doctors to examine patients' internal structures in great detail because of differences in absorption between bone and soft tissue.

Additionally, the thickness and density of Earth's atmosphere prevents the sun's more strong X-ray emission, which is lower in number but still potent, from reaching the Earth's surface.

Electrons

A particle's velocity and charge quantity are all that's needed to determine the inelastic cross-section of the first-born approximation Therefore, the stopping power of an electron and a positron travelling at the same speed should be the same as that of a proton. For an electron, the indistinguishability between the atomic and incident electrons makes a difference in practice. Convention dictates that the more energetic of the two electrons that arise from an incident electron is referred to as the primary. Amount of power that can be lost is equal to half the amount that can be absorbed. As a result, the stopping point for an electron is supplied by a complex equation that incorporates this effect; i.e., The stopping number of heavily charged particles is configured differently.

$$B_e = \frac{Z}{2} [\ln mc^2 \beta^2 E/ 2I^2 - (1- \beta^2) – (2 \sqrt{1 - \beta^2} -1 + \beta^2$$

$$\ln 2 + (1 – \beta^2) + \frac{1}{8} (1- \sqrt{1 - \beta^2})^2 - 2 \frac{C}{Z} - \delta]$$

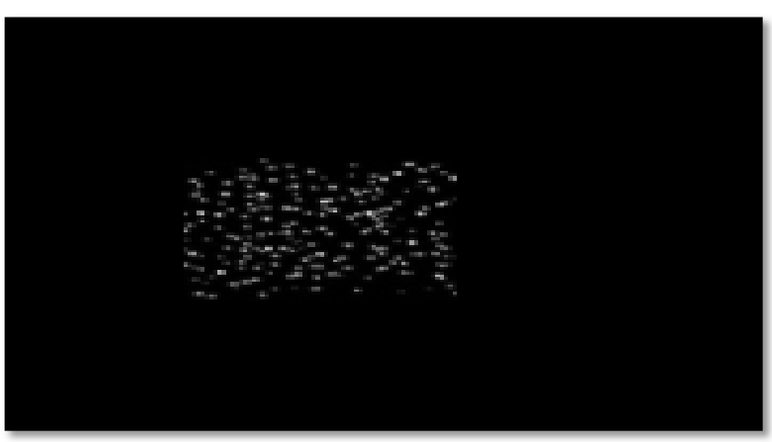
The stopping power of this formula can range from a few 100 electron volts to a few million electron volts in materials with a low atomic number, depending on the substance. Due to the increasing breakdown of the Born approximation, it is no longer possible to access high-energy states by transitions at low velocities. The electron-stopping-power formula, on the other hand, maybe extended down to 50 eV with a few minor adjustments. It is not recommended to use any stopping-power formula with a value less than that. The great majority of the energy stored in electronic states with only a few electron volts remaining is lost by radiation.

Electron stopping power increases exponentially with increasing velocity due to relativistic phenomena. When the electron velocity approaches the speed of light (v/c =β 1), the relativistic stopping power tends to infinity, except for the polarization screening term. The restricted stopping power equals one-half of the stopping power and is mathematically equal to linear energy transfer. The Fermi plateau is a constant

value that fluctuates in a smooth manner as the ratio approaches unity. Unrestricted stopping power, on the other hand, increases indefinitely, although its impact on relativistic velocities (those close to the speed of light) is negligible compared to nuclear collisions.

The photons in gamma (γ) radiation have a wavelength smaller than $3x10^{-11}$ meters, making it invisible to the human eye (greater than 10^{19} Hz and 41.4 keV). [4] After nearly all nuclear events, gamma ray emission occurs as a means of removing excess energy from an unstable nucleus. Because of their mass and electric care, alpha and beta particles are likely to interact with other atoms as they travel. Unlike alpha and beta radiation, which have mass and electric charge, gamma radiation is composed of photons without these qualities, allowing it to travel far farther through matter.

A thick or dense layer of material can be used to halt gamma rays regardless of whether that material has a high or low density along the radiation's path. Metals like lead and depleted uranium, which have huge numbers of protons and neutrons, can provide 20% to 30% more stopping power than less dense and lower atomic weight metals (such as water or concrete). There is no way for space radiation to reach Earth because the atmosphere absorbs all gamma radiation. Gamma rays can be slowed down by half by passing through 500 feet of fresh air (150 m).



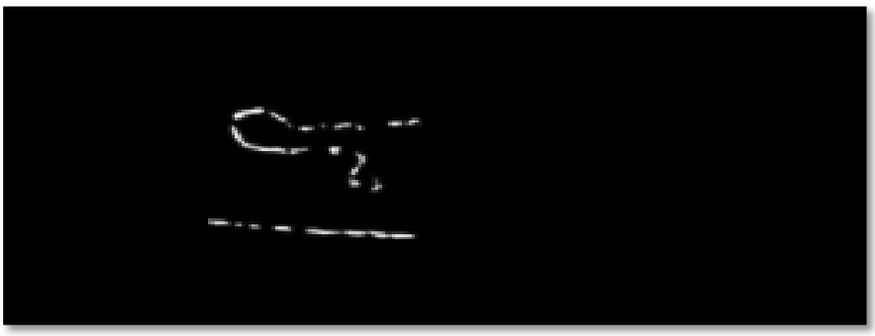
Particles of alpha symmetry Nuclei of Helium-4 form (two protons and two neutrons). Due of the charges they carry and the combined mass of both, they have a powerful interaction with matter, but because of their normal velocities, they can only travel through air or low density material for a few centimeters at a time (the thin mica material used in some Geiger counter tubes, which allows alpha particles to enter, for example). Therefore, alpha particles from conventional alpha decay do not injure living tissues below because they don't get into the outer layers of dead skin cells. Alpha particles with enormous energy make up a small percentage of cosmic

rays, yet they are powerful enough to penetrate the human body and even thin metal plates. Since the Earth's magnetic field deflects and then stops them, they are solely a threat to astronauts.

When alpha-emitting radioisotopes are consumed or inhaled, they pose a risk to the health of the individual (breathed or swallowed). Alpha radiation can harm living tissue if it comes into contact with the radioisotope. For the same amount of energy. Alpha particles(α) cause at least 20 times more cell damage than X-rays or gamma rays. The topic of relative biological efficacy is addressed in further detail in that article. Radium, radon, and polonium isotopes are all examples of alpha-emitters that are extremely dangerous because of the rapid decay that occurs in such short-lived materials. (β−)

An emitted electron is the source of the beta-minus (-β) radiation It is more penetrating than alpha radiation, but not as penetrating as gamma radiation. A few centimeters of plastic or a few millimeters of metal can suppress beta rays from radioactive decay. Nuclear nuclei release the antineutrino and the beta particle, which is a byproduct of the breakdown of a neutron into an atom. Linac accelerator beta radiation is much more energetic and penetrating than naturally occurring beta radiation. Subcutaneous cancers are treated with it therapeutically in radiotherapy.

Positron emission, which is the antimatter form of electron emission, is referred to as beta-plus (+β) radiation. To destroy an electron, a positron must slow down to a speed comparable to that of the material's electrons. This causes the positron to emit two 511-keV gamma rays in the process. This means that the two gamma photons drive be moving in the exact opposite direction from one another. In addition to being ionizing, High-energy photons are present in the high-energy gamma radiation emitted by positron annihilation during nuclear fusion.



Neutron radiation

A neutron's speed or energy is used to characterize it. Neutron radiation is made up of free neutrons. Therefore, these neutrons can be created in both natural and induced nuclear fission reactions, depending on the situation. The production of neutrons is rare, but when chain reaction fission or fusion reactions are ongoing, they produce significant quantities of neutrons. The generation of neutrons in a nuclear reactor ceases almost immediately when the reactor reaches non-criticality, which occurs for around 10 microseconds in a thermonuclear explosion or continually inside a functioning nuclear reactor.

Neutrons have the ability of irradiating other objects and materials. The neutron activation method is the most widely used method for producing radioactive sources for use in medical, academic, and industrial research and development. Even low-speed thermal neutrons can activate neutrons, despite their relatively modest speed (in fact, they cause it more efficiently). Unlike charged particles like protons and electrons, neutrons do not ionize atoms by excitation of an electron. Ionization is caused by their absorption by nuclei that become unstable as a result. Thus, neutrons are described as "indirectly ionizing." Even neutrons with low kinetic energy are ionizing, and so pose a considerable radiation hazard. The most common isotopes of both sorts of atoms present (hydrogen and oxygen) in water, for example, catch neutrons and become heavier, but they remain stable forms of those atoms.

Activating a hydrogen atom takes more than one neutron, a statistically infrequent occurrence, whereas oxygen requires two more neutrons. Thus water is only very weakly capable of activation. Sodium found in seawater, on the other hand, requires just one neutron to transform into Na-24, an extremely potent beta decay source, with a half-life of 15 hours.

Additional advantages include the ability of high-energy, high-speed neutrons to atoms. As the chemical connection is broken, high-energy neutrons can ionize atoms by striking their nuclei and knocking them out of a molecule. This process can leave one or more electrons behind. Chemical free radicals are formed as a result of this. "Neutron Spallation" or "Knockout" is another way neutrons can create ionizing radiation. When neutrons contact atomic nuclei (particularly hydrogen nuclei), they trigger the release of high-energy protons. Last but not least, similar to a billiard ball striking another, the proton receives the majority of the neutron's energy. Direct ionization occurs as a result of the charged protons and other reaction products.

High-energy neutrons can travel small distances in typical solids (a few millimeters) in addition to air travel (hundreds or even thousands of meters) (few meters). To keep them at a distance greater than one meter, it's usually required to use a hydrogen-rich shielding substance like concrete or water. Due to the fact that nuclear reactors have a meter-thick water layer that acts as an effective screen against neutron radiation, it is a common source of neutron radiation.

Cosmic radiation

The sun and deep space are the two primary sources of high-energy particles that reach the Earth's atmosphere. Coronal mass ejections (CMEs) occur when the sun releases particles, mostly free protons, into the solar wind on a regular basis (CME).

Inter- and extra-galactic cosmic rays are far less common, although they have much higher energy. In addition to protons, Helions make up the great majority of these particles (alpha particles). Ionized nuclei of heavier elements can be found. They are not sure where these galactic cosmic rays come from, but the magnetic fields of supernovae and in particular gamma-ray bursts (GRB) appear to be capable of the huge accelerations that these particles have reported. This is not the case, however. Quasars, galaxy-wide jet phenomena similar to GRBs but much larger in scale, may also be the source of these bursts of light, which may have been a violent aspect of the world's early past.

Non- ionizing radiation

The electromagnetic spectrum

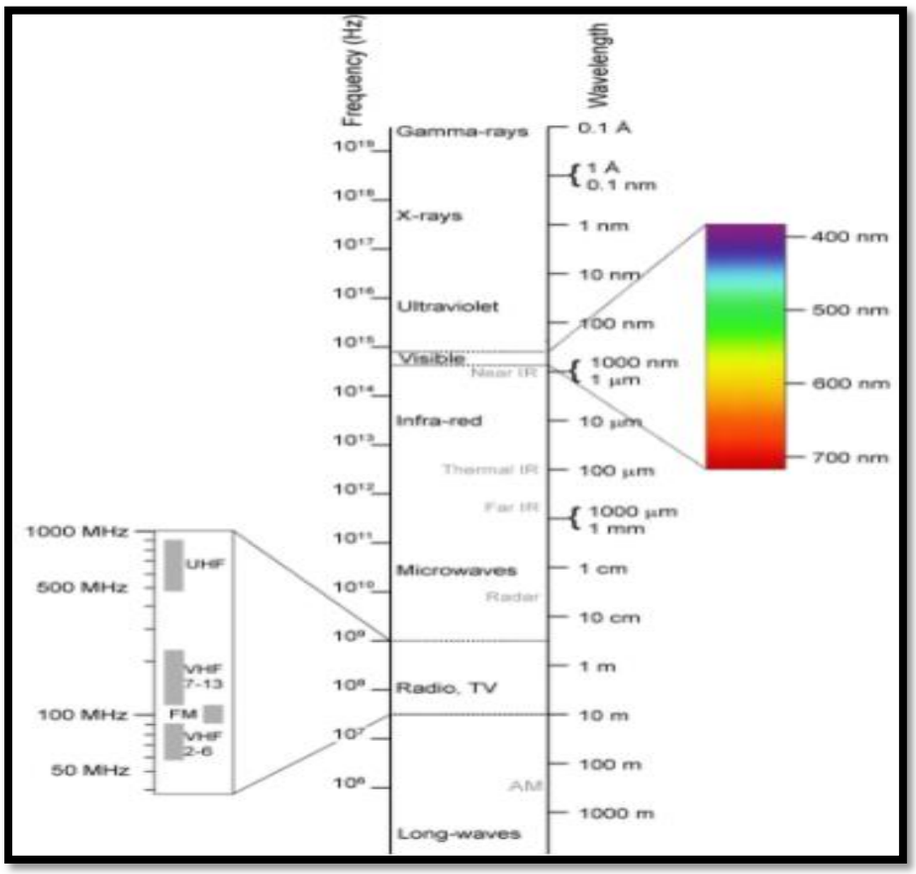
When non-ionizing radiation particles move through matter, their kinetic energy is too low to create charged ions. Only the rotating, vibrational, or electronic valence configurations of atoms and molecules may be changed by non-ionizing electromagnetic radiation (see the categories below). Only lately have non-ionizing radiation's effects on live tissue been examined. However, non-ionizing radiation has diverse biological consequences depending on the kind.

"Non-ionizing" radiation can cause thermal-ionization with enough heat to bring temperatures to the ionization energies. In contrast to ionization radiation, which uses only one particle to ionize an object, these processes take place at a far greater energy. Thermal ionization may be seen in the flame-ionization of a typical fire, as well as the browning processes generated during broiling-type cooking, infrared radiation.

The range of all possible frequencies of electromagnetic radiation is known as the electromagnetic spectrum. The electromagnetic spectrum of a piece of equipment refers to the typical distribution of electromagnetic radiation emitted or absorbed by the item (sometimes shortened to spectrum).

Radiation that does not ionize is consisted of electromagnetic waves (as quanta or particles, see photon) that are not powerful enough to separate electrons from atoms or molecules and so do not produce ionization. These include radio waves, microwaves, infrared, and visible light. Although it is theoretically possible for lower frequencies of UV radiation to generate chemical and molecular changes and damage similar to ionization, this isn't necessarily the case. All X-rays and gamma rays emit their energetic particles at the highest frequencies of ultraviolet light, which is where ionization occurs.

It is not the amount of particles or waves that determines ionization, but their energy. As long as the particles or waves being bombarded aren't high enough in energy to be considered ionizing, they won't affect the temperature enough to induce minuscule percentages of molecules or atoms to ionize by thermal-ionization (Although this can be done, it requires extremely high radiation levels).



Ultraviolet light

The lesser portion of the ultraviolet spectrum, known as soft UV, is non-ionizing, from 3 eV to around 10 eV. Non-ionizing UV, on the other hand, has such damaging effects on chemistry and biological systems that it is often equated to ionizing radiation, (including oxidation, mutation, and cancer).

visible light

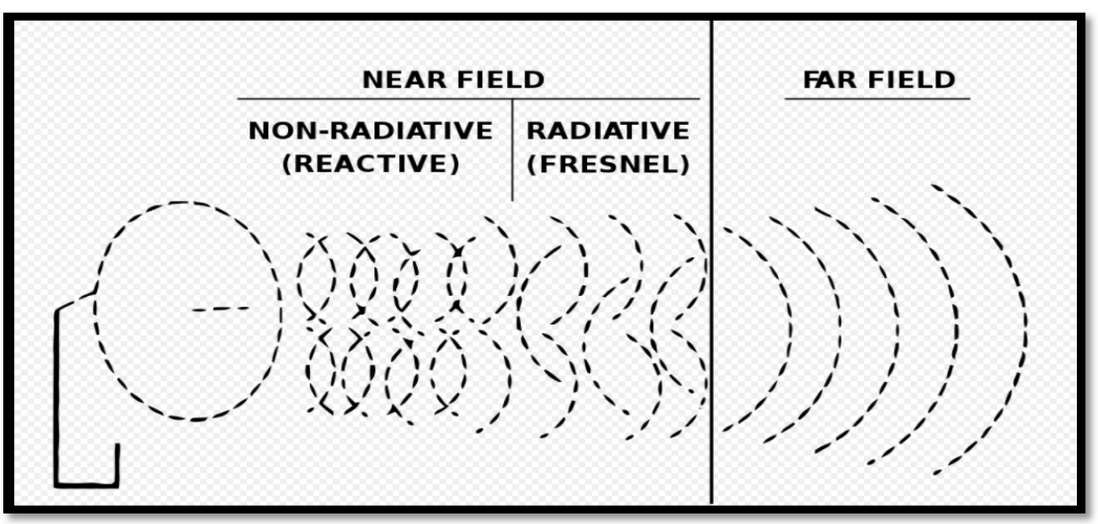
In the electromagnetic radiation, light, also known as visible light, remains a relatively small band of electromagnetic radiation with a wavelength that is visible to the human eye. The wavelength range is 380–750nm, which corresponds to a frequency range of 790 to 400 THz. Scientists refer to all electromagnetic energy as "light," regardless of whether or not it is visible.

Infrared

Electromagnetic radiation includes infrared light. The wavelength of infrared (IR) light ranges among 0.7 and 300 micrometers, which is equivalent to a frequency range of 430 to 1 terahertz. The wavelengths of infrared light are longer than those of visible light, but they are shorter than those of microwaves. At a distance from the emitting items, "feel" can be used to detect infrared light. The "pits" on the heads of infrared-sensing snakes allow them to detect and concentrate infrared using a pinhole lens. Sea level irradiance is little over 1 kilowatt per square meter in bright sunshine. This energy is consists of 53% infrared radiation, 44% visible light, and 3% ultraviolet radiation.

Microwave

Microwaves with wavelengths as short as one millimeter and as long as one meter are known as microwaves, and are electromagnetic waves, and they operate between frequencies of 300 MHz and 300 GHz. UHF and EHF (millimeter waves) are included in this broad definition, in any case, different sources utilize different restrictions. A minimum of the whole super high frequency spectrum (3 to 30 GHz, or 10 to 1 cm) is always present in microwaves; radio frequency engineers often consider one GHz (30 cm) to be the lower border, and 100 GHz to be the upper limit(3mm)



If you draw a sphere around an antenna, you'll get the same amount of radiation energy no material how far away from the antenna you draw it, because the

electromagnetic field radiating into infinite space declines in strength according to an inverse-square rule of power. The far field of electromagnetic radiation exists in addition to the electromagnetic field created by the transmitter. The changing electromagnetic field includes the "near-field," which is in close proximity to the transmitter, but it does not count as electromagnetic radiation.

Radio waves

While infrared light has shorter wavelengths, radio waves, a form of electromagnetic energy, has a greater wavelength. Electromagnetic waves move at the speed of light in all directions at once. Lightning and a wide range of celestial objects are just a few examples of the natural events that can emit radio waves. Whether it is fixed or mobile communication, broadcasting or navigation systems, satellites or computer networks all utilise these technologies in some way or another. As a result, radio waves emitted by almost any alternating current wire are referred to as interference. Long radio waves can bend at the Earth's curvature and cover a huge region of the planet, whereas short radio waves bounce off the ionosphere and Earth and bounce off of each other to travel across the world. In general, shorter wavelengths bend and reflect less than longer wavelengths, allowing them to proceed in a more direct path forward.

Very low frequency

In terms of wavelengths, VLF refers to frequencies between 30 Hz and 3 kHz, which are about 100,000 and 10,000 meters in length. For radio navigation, only the simplest signals may be delivered due to the lack of bandwidth in this area of the radio spectrum. Because the wavelengths range from ten to one myriameter, it is also known as the myriameter band or the myriameter wave (an obsolete metric unit equal to 10 kilometers).

Extremely low frequency

A source of extremely low frequency (ELF) radiation produces radiation with frequencies ranging from three hertz (Hz) to thirty hertz (Hz) (108 to 107 meters respectively). In the field of atmospheric science, different definitions are employed,

ranging from 3 Hz to 3 kHz in frequency. (4) In the related science of magnetosphere, lower frequency electromagnetic oscillations (pulses occurring below 3 Hz) are recognized as belonging to the ultralow frequency (ULF) range. which is likewise classified differently from the ITU Radio Bands. Submerged submarines can receive extremely sluggish signals from an enormous military ELF antenna in Michigan.

Thermal radiation (heat)

The term "Thermal radiation" refers to the infrared radiation released by objects at temperatures commonly seen on Earth. The term "thermal radiation" encompasses both the actual radiation and the process through which an object's surface emits black body radiation to release its stored thermal energy. Thermal radiation includes infrared or red radiation emitted by a standard home radiator/electric heater, as well as the heat emitted by a functioning incandescent light bulb. To produce thermal radiation, atoms' charged particles transform their movement into electromagnetic radiation.

Temperature-ionization can occur even with low-frequency thermal radiation, as described above, if it deposits enough thermal energy to raise temperatures sufficiently. The ionization (plasma) that occurs in everyday fires and the molecular changes generated by food cooking's "browning" (the chemical reaction that starts with a significant amount of ionization as a starting point) are two notable instances of this.

Radiation a black-body

For example, the idealized spectrum of black-body radiation is emitted by a body with the same temperature everywhere around. Body temperature determines the shape of the spectrum and the quantity of energy released by the body. In terms of power/unit-area, Planck's radiation law describes the intensity of the radiation, which is spread throughout the whole range of electromagnetic frequencies. Radiation from a black body has a maximum intensity at a certain frequency for each black body temperature value. As the body's temperature rises, so does the maximum radiation frequency, moving upward in frequency. The maximum frequency of black-body radiation is determined by Wien's displacement equation and is dependent on the temperature of the object. A black-body emits as much radiation as feasible at any given wavelength, regardless of the temperature. A black body will also soak up as

much incoming radiation as possible, regardless of wavelength. The color of a black body with a temperature below that of the surrounding environment would appear black if it reflected no light or emitted enough radiation at visible wavelengths for human eyes to perceive it. In theory, a black-body generates electromagnetic radiation that spans the full electromagnetic spectrum, from low-frequency radio waves to x-rays.

Temperature may be determined from the hue of a radiating black-body. As the peak radiation moves through the visible spectrum's red (2,500K), yellow (5,800K), white, and blue-white (15,000K) regions, it determines the hue of stars. It is black when the peak is below the spectrum and blue when it is above, as all visible hues are represented in decreasing order of intensity from blue \ red.

Discovery

The discovery of electromagnetic radiation with wavelengths extra than visible light dates back to the early nineteenth century. William Herschel, an English astronomer, is credited with discovering infrared light. Prior to the Royal Society of London's meeting in 1800, Herschel reported his findings. As a result of an increase in temperature observed by a thermometer, Ritter discovered the infrared spectrum (beyond the red spectrum) using a prism to reflect sunlight. Herschel followed suit.

Johann Wilhelm Ritter, a German scientist, discovered ultraviolet ray in 1801 by finding that prism-emitted light browned silver chloride more quickly than violet light did. What would become photography had its roots in Ritter's early scientific endeavors. Chemical reactions can be induced by ultraviolet rays, according to Ritter's research.

Natural radio waves were not the first to be detected, Heinrich Hertz, a German physicist, created radio waves in 1887 using electrical circuits designed to produce oscillations in the radio frequency range based on the equations of James Clerk Maxwell.

X-rays were discovered and named by Wilhelm Röntgen. This happened while he was doing experiments by high voltages practical to an evacuated tube on November 8th, 1895. X-rays' primary qualities, which we still understand today, were discovered in less than a month thanks to his work.

Henri Becquerel discovered in 1896 that rays emitted by certain minerals pierced black paper and produced fogging of an unexposed photographic plate. Marie Curie, a doctorate student of his, found that only specific chemical elements emitted these rays. Her term for it was "radioactivity" because of the frequency at which she displayed this behavior.

Ernest Rutherford in 1899 used basic testing to distinguish between alpha and beta rays (alpha particles). A general pitchblende radioactive source was used by Rutherford to establish that the rays emitted by the source penetrated different materials. Alpha rays were called by Rutherford because of their positive charge and brief penetration (they were stopped by paper). Beta was given its name by Rutherford because of its negative charge and the fact that it was more penetrating (it could expose film through paper but not metal). Radiation seen in uranium salts was first detected by Becquerel in 1879. After Paul Villard discovered a third neutrally charged and exceptionally penetrating form of radium radiation in 1900, Ernest Rutherford realized this must be yet another kind of radiation. Rutherford dubbed these gamma rays in 1903 as a result.

Alpha and beta particles were discovered by Rutherford and Royds in 1909, and Becquerel established that beta rays are rapid electrons. gamma rays were discovered in 1914 by Rutherford and Andrade, who proved that they are similar to X-ray photons in terms of wavelength.

On a free balloon trip in 1912, the scientist Victor Hesse brought along an electrometer and tested it at various altitudes, which enabled him to provide the first unequivocal detection and demonstration of the existence of cosmic ray radiations reaching the Earth from outer space. In later years, it was only with increasing clarity that the nature of these radiations was finally grasped.

Chadwick discovered neutron radiation in 1932 when he discovered the neutron. After that, other high-energy particles, such as positron and muon radiation, were identified by cloud chamber investigation of cosmic ray reactions, and another particle radiation was produced artificially in particle accelerators in the second half of the 20th century.

Applications

Medicine

Radiation and radioactive substances are used in medical diagnosis, treatment, and research. and research. Thick tissues like bone and cartilage block X-rays from penetrating through. It is via the use of X-rays that doctors are able to detect damaged bones as well as cancerous growths in the body. The radiation emitted by a radioactive material can also be used by doctors to detect certain disorders, such as cancer, in the human body. To distinguish it from other kinds of radiation, radiation used to treat cancer is known as ionizing radiation because it releases electrons from atoms in the cells it passes through. This can either kill cells or alter the DNA of the cells such that they are unable to reproduce. Non-ionizing radiation includes radio waves, microwaves, and light waves. ionizing cells is not possible since they lack the necessary energy.

Communication

Electromagnetic radiation is used in all modern communication systems. When the radiation's strength changes, the sound, images, or other data being communicated also changes. Because the wave is modulated to match the sound, A radio wave or microwave, for example, can be used to transmit it. Additionally, musicians have explored the use of radioactive radiation to create sound and music via gamma ray sonification.

Science

Researchers use radioactive isotopes to determine the age of materials that were previously alive. These kinds of artefacts can be dated using a technique known as radiocarbon dating, which counts the amount of radioactive carbon in them. Rocks and other geological structures can also be dated using additional radioactive elements (and even some man-made objects). Radiometric dating is the name given to this method of dating. A radioactive atom known as tracer atoms is used by scientists to detect the migration of pollutants in the environment.

Radiation is used to determine the composition of materials in a course called neutron activation analysis. In this process, scientists bombard a sample of a

substance with particles called neutrons. Some of the atoms in the sample absorb neutrons and become radioactive. The scientists can identify the elements in the sample by studying the emitted radiation.

Possible damage to health and environment from certain types of radiation

In some circumstances, ionizing radiation can cause cancer or genetic damage to living organisms. Human damage such as burns can be caused by non-ionizing radiation when it is present in the right amounts and circumstances. To add microwave and millimeter waves to its list of possible carcinogens, In 2011, the World Health Organization's International Agency for Research on Cancer (IARC) announced its findings on cancer.

RWTH Aachen University's EMF-Portal web site presents one of the biggest records about the effects of Electromagnetic radiation. As of 12 July 2019, it has 28,547 publications and 6,369 summaries of individual scientific studies on the effects of electromagnetic fields.

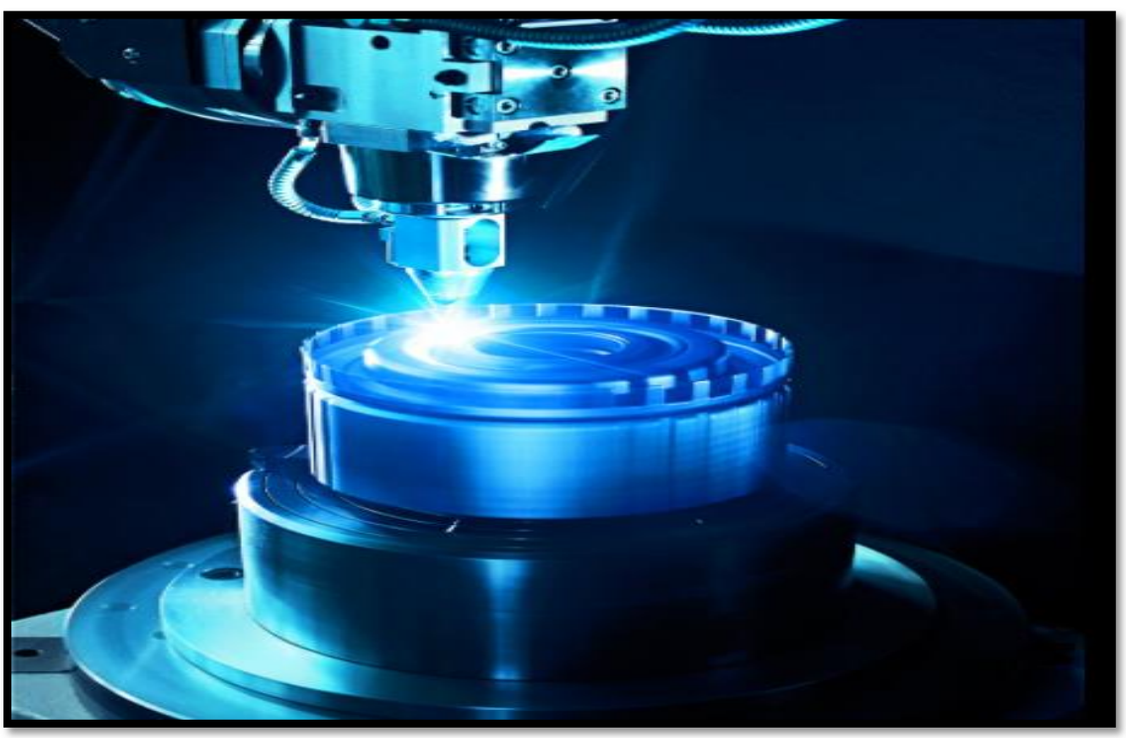
1-1 Lasers

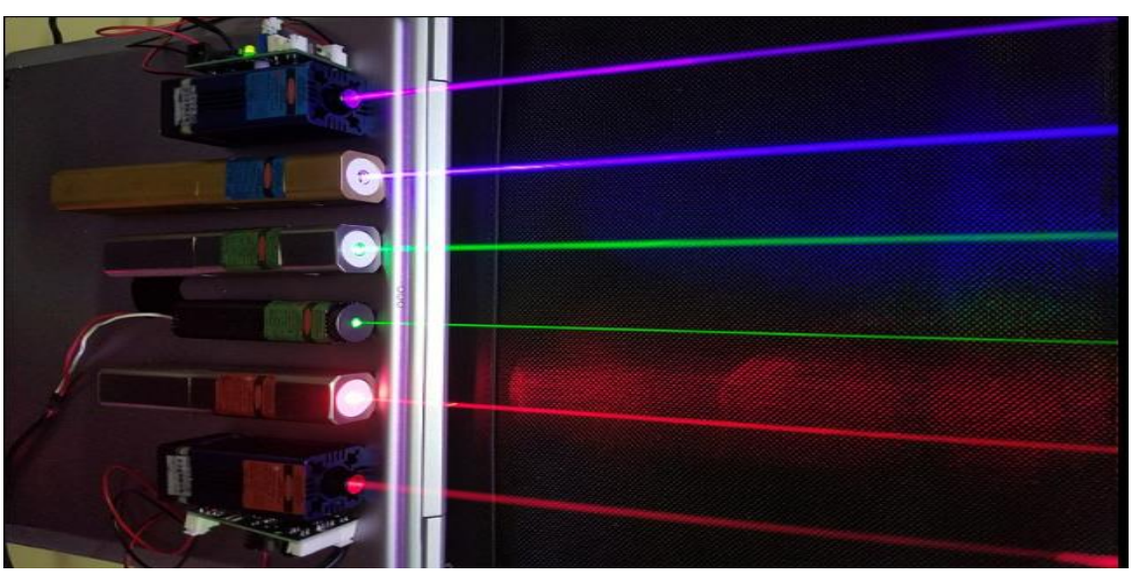
Electromagnetic radiation acts as a stimulant. a laser emits light through an optical amplification process. "Light amplification by stimulated emission of radiation" is the abbreviation for the term "laser." According to Charles Hard Townes and Arthur Schawlow's theoretical work, Theodore H. Maiman built the first laser in 1960 at Hughes Research Laboratories, which was based on previous theoretical work.

A laser's ability to emit coherent light distinguishes it from other light sources. Cutting with lasers and lithography are made possible by laser technology. This is referred to as "coherence of space," and it is what allows a laser to be focused on a small area. Due to spatial coherence, laser pointers and lidar are made possible, as a laser beam can remain narrow even over long distances (collimation). Lasers can produce light with an extremely narrow spectrum when they have a high temporal coherence. It is also possible to generate ultrashort pulses of light that have a broad spectrum but short durations by utilizing temporal coherence in this manner.

From optical disc drives to barcode scanners to DNA sequencing tools to fiber optics to semiconductor chip fabrication, there is a vast variety of optical and laser-based equipment in use today (photolithography). Besides laser surgery and skin treatments, lasers are also used to cut and weld materials, to mark targets and

measure range and speed in the military and law enforcement, as well as in laser lights displays for entertainment. To generate fluorescence and act as a white light source, In some cases, lasers operating in the blue to near-UV range have been utilized in place of light-emitting diodes in order to improve efficiency (LEDs). It is feasible to have a considerably smaller emitting area while eliminating the droop that LEDs encounter; such devices are now being used in some automotive headlamps.

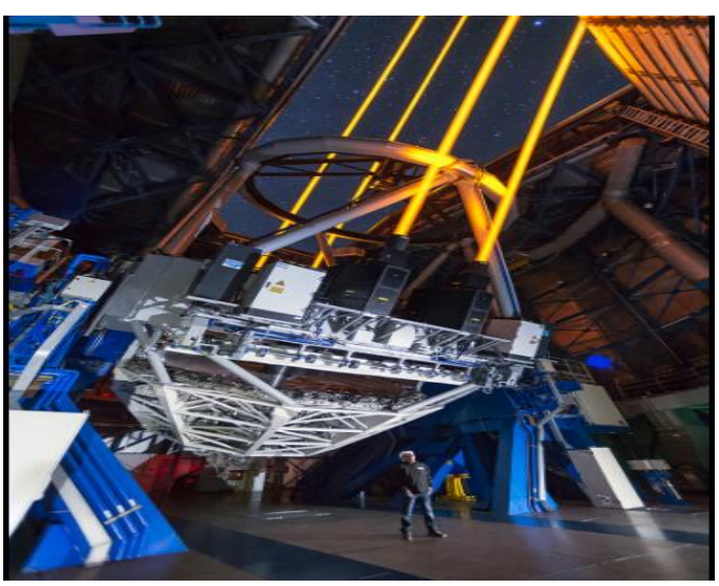




Fundamentals

Lasers stand out from other light sources because of their high levels of coherence. Diffraction-limited narrow beams are produced when spatial (or transverse) coherence is maintained. For high irradiance, laser beams can be hyper-focused, or they can have a very low divergence, which allows the beams to concentrate their power across a large region.

A single-frequency polarized wave, whose phase is associated over a relatively long distance (the coherence length) along the beam is referred to as temporal (or longitudinal) coherence. Thermal or incoherent light sources have an extremely low coherence duration because the instantaneous amplitude and phase of the beam are random with respect to both time and location. In a vacuum, the wavelength is what gives lasers their unique properties. There are many distinct modes of operation for "single wavelength" lasers, however, they all produce radiation with somewhat varied wavelengths. Although the term "temporal coherence" implies a certain amount of monochromaticity, Lasers may simultaneously emit a wide range of light wavelengths or a wide spectrum of light. The diffraction limit is exceeded by some lasers because they do not operate in a single spatial mode. All of these technologies are referred to as "lasers" because they use the stimulated emission mechanism to produce light. Employing lasers is preferable than using simpler technologies when the desired spatial or temporal coherence cannot be achieved by other means.



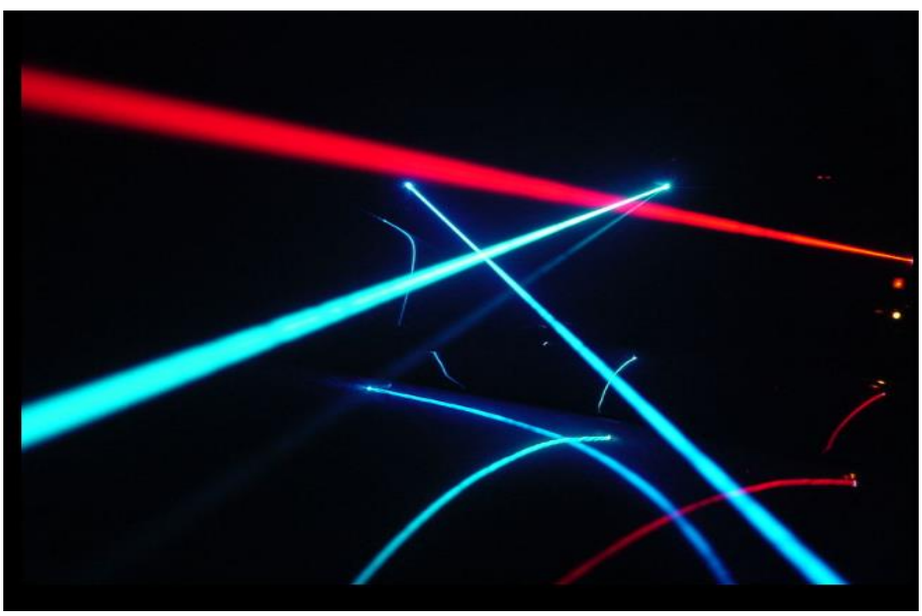
Terminologies

Fog-reflecting laser beams on the windshield of a driving automobile When amplification by stimulated emission was first developed, it operated on microwave frequencies, and it was given the moniker "maser," which is an abbreviation for "microwave amplification by stimulated emission of radiation." Today, amplification through stimulated emission operates at a variety of frequencies. Until the word "microwave" was replaced with the word "light" in the acronym, comparable optical devices were referred to as "optical masers."

Lasers refer to any device that operates at a frequency above microwaves (Infrared, ultraviolet and gamma-ray lasers are also included). Masers refer to any device that operates at microwave or lower frequencies.

An optical oscillator, not an optical amplifier, is what the name refers to when it generates its own light. " Excitation of the ionization process results in the oscillation of light. "would have been a more accurate abbreviation for the term LOSER. Laser amplifiers have become a common noun as a result of the widespread use of the original acronym.

To lase is a back-formed verb that means "To give out coherent light," and is widely used in the area, particularly in regard to the gain medium of a laser; while a laser is working, it is referred to as "lasing." When there is a coherent state that is not related to any produced device, the terms laser and maser are also used, With astrophysical masers and atom lasers, for example, the terms are not used.

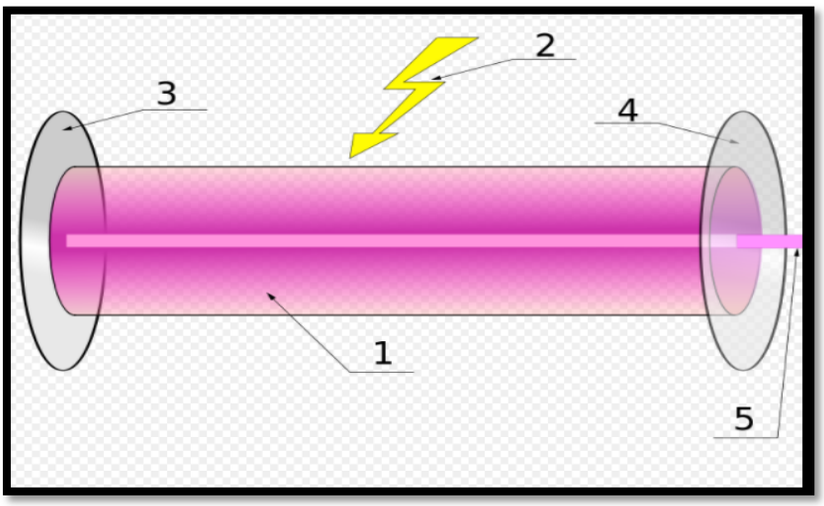


Design

A laser is made up of three parts: a gain medium, an energizing mechanism, and something that provides optical feedback. Using stimulated emission, It is possible to magnify light via amplification using an amplification gain medium, which has qualities that allow it to do so. Mediums with a high gain are used to increase the amount of light that goes through them at a specific wavelength (rises in power). The response permits stimulated emission to raise largely the optical frequency at the peak of the gain-frequency curve, which is the case in the vast majority of cases. As the number of stimulated emissions grows, one frequency eventually becomes dominant over the others, resulting in the formation of coherent beams. An analogy to an audio oscillator with positive feedback could be a speaker in a public address system that is situated close to a microphone, which is how stimulated emission works. The audible scream is caused by audio oscillation at the apex of the amplifier's gain-frequency curve. Gain medium amplification is dependent on a pumping process that involves the injection of energy into the medium. A typical method of delivering energy is by the use of an electric current or light with a certain wavelength. To illuminate the pump's internals, a flashlight or a laser with a similar wavelength can be utilized.

Lasers that use feedback from an optical cavity (two mirrors at either end of the gain medium) account for the vast majority of all lasers on the market. The light is amplified as it bounces back and forth between the gain medium and the two mirrors. It is not uncommon for the output coupler to be somewhat transparent. Through this mirror, some light is able to elude us. A wide or narrow laser beam is produced depending on how the cavity is constructed (whether the mirrors are flat or curvy.) Laser oscillators are sometimes referred to as such since they are similar to electrical oscillators.

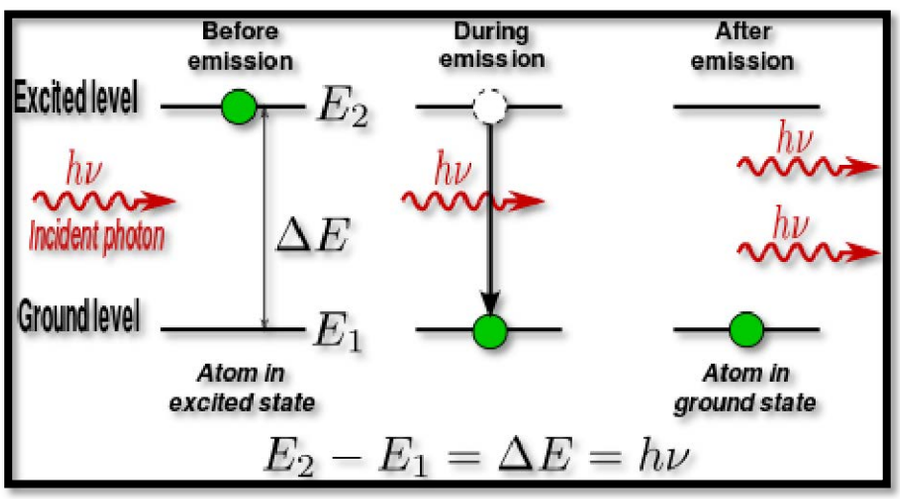
The majority of practical lasers have extra features that influence the properties of the emitted light, such as polarization, wavelength, and beam shape, among other things.

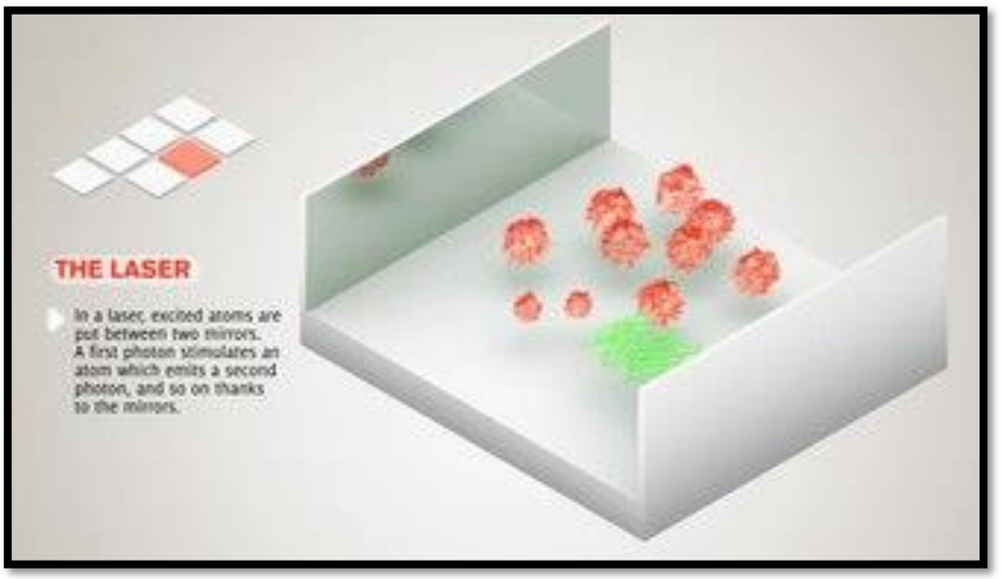


When it comes to chemistry and physics, electrons and their interactions with electromagnetic fields are critical concepts to understand.

Emission induced by a stimulation

According to classical physics, an electron's energy increases as it moves away originating in the nucleus of an atom, Quantum mechanical processes, on the other hand, need electrons to occupy discrete places in orbitals. There are two distinct energy states in an atom where electrons can be found, as indicated below:





To absorb energy from light or heat (phonons), an electron in an atom must be in a transition between two energy levels that match to the photon's energy levels. Light can only be absorbed at a single wavelength by any given transition. A photon with the suitable wavelength can force an electron to move from one energy level to another. As a result, a photon is extinguished.

It is not possible for an electron to remain in the same state for an indefinite period of time when it is excited from one energy level to another with an energy difference of E. The vacuum will eventually spontaneously produce a photon with energyΔE, which will then be released into the universe. As a means of conserving energy, Transitions to lower energy levels that are not now occupied by the electron occur at different times, with the time constants of the transitions to different levels fluctuating. "Spontaneous emission" is the term used to describe this procedure. An accidental emission is a quantum-mechanical event that serves as a physical representation of the Heisenberg uncertainty principle; Despite the fact that the emitted photon has a random orientation, its wavelength matches that of the transition's absorption spectrum. Fluorescence and heat emission are generated and monitored using this method. Fluorescence and heat emission are mechanisms.

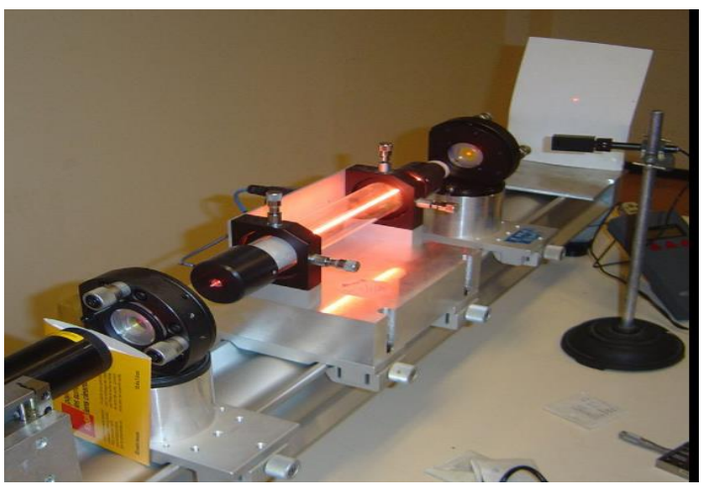
Photon absorption by transitions can also result in an electron falling from a higher level to a lower one, which emits another photon in the same wavelength. In terms of wavelength, phase, and direction, the emitted photon is identical to the initial photon. Stimulated emission is the name given to this phenomenon.

In order to activate the gain medium, a source of external energy must be used. If an electrical field or an external light source is utilized, the medium will typically contain an excitation medium made of particles that have been excited into such a state by the use of such an external source of energy.

Typically, the gain medium in a laser is a material with precise control over its purity, size, concentration, and form, and it magnifies the beam by the process of stimulated emission, which is discussed in this section. This chemical can exist in a variety of states including gas, liquid, solid, and plasma. When the pump energy is absorbed by the gain medium, it causes some electrons to be raised into higher-energy quantum states (known as "excited" state). Light-interacting particles can either absorb or emit photons. Both spontaneous and induced emissions are possible. Photons are released in the same direction as the light, in this situation. It is possible to have a population inversion when the number of particles in one excited state surpasses the number of particles in a lower energy state. The light is amplified because the rate of stimulated emission exceeds the rate of light absorption in the medium when this condition exists. For example, an optical amplifier has this property. It's possible to create lasers by placing an optical amplifier in an optical cavity.

Although using a resonator is preferred, it is not necessary in order for light to be amplified sufficiently in a single pass through the lasing material with extraordinarily high gain, which is generally referred to as super-luminescence, to occur. Contrary to popular belief, although such a device (for example, the nitrogen laser produces light that has the spatial and temporal coherence of a laser, the light it produces does not have the same properties as lasers. Instead of acting as an oscillator, this device functions as a high gain optical amplifier, amplifying the spontaneous emission of the device. The same process is utilized by astrophysical masers and lasers to produce their light beams. The optical resonator is frequently referred to as an "optical cavity," although this is a misnomer because lasers use open resonators rather than the actual cavity that would be used at microwave frequencies in a maser. There are two mirrors in the resonator, one in front of the other, between which a coherent beam of light travels in both directions, reflecting back on itself such that an average photon will pass through the gain medium multiple times before it is discharged through the output aperture. Using recirculating light, it is feasible to raise the gain (amplification) in the medium exponentially, exceeding the loss (decrease) in the resonant chamber's losses.

The gain of the medium is reduced by the same amount when an atom is caused to emit and then returns to its ground state. With increasing beam power, gain medium saturation occurs when the net gain (gain minus loss) approaches unity. Pump power in continuous-wave lasers is balanced against gain saturation and cavity losses at an equilibrium point, and this equilibrium value is utilized to determine the operating point. If the pump power is insufficient to overcome the losses in the cavity, laser light cannot be produced. The lasing threshold is the smallest amount of pump power required to cause laser activity to occur. Only photons traveling in a spatial model that is supported by the resonator, on the other hand, will pass through the advance medium more than once and receive significant amplifying effects.



A laser demonstration using helium–neon gas. An electric discharge is the source of the tube's central glow. The laser's gain medium is this incandescent plasma. On the right side of the screen, a small yet intense dot is produced by the laser. Because of the overexposure, the spot's center appears white.

The emitted light

In most lasers, the first stage in lasing is often accomplished through spontaneous emission into the lasing mode. Amplification occurs by the use of stimulated emission, which is amplified in the gain medium, which is amplified even further. Light with the same polarization, wavelength, and direction as the input signal is generated via stimulated emission; however, this light is out of phase with the stimulating signal by 90 degrees, which is known as phase shift. The filtering action of an optical resonator contributes to the characteristic coherence of laser light, as well as uniform polarization and monochromaticity, depending on the design of the resonator. When compared to the linewidth of light emitted by a passive resonator,

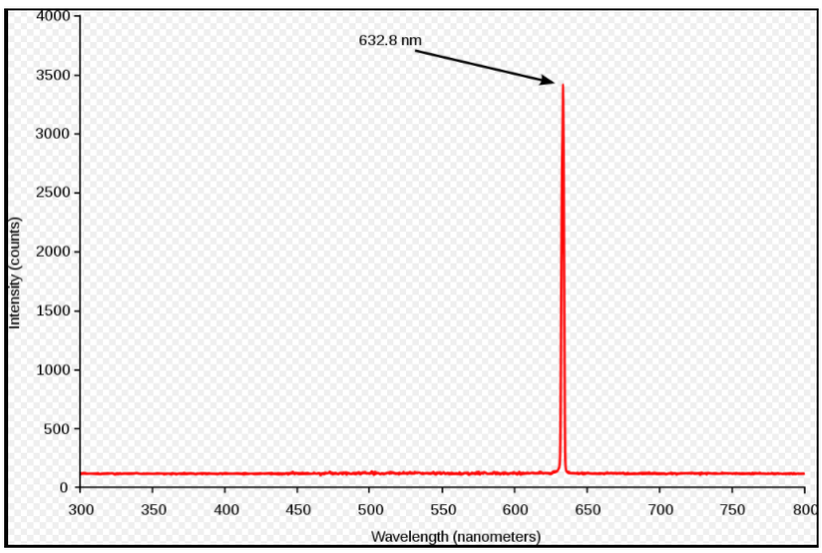
the fundamental laser linewidth of a lasing resonator can be orders of magnitude less. On some lasers, the injection seeder is utilized to start the process with a highly coherent beam, which is beneficial. It is possible to make spectral beams with a narrower bandwidth using this technique.

The Nobel Prize in physics was awarded to Roy J. Glauber in 1963 for his work demonstrating that coherent states can be created by combining photon number states. In order to create a coherent beam of light, the quantum photon states are distributed using a Poisson distribution. A laser beam's photon arrival rate is therefore described using Poisson statistics.

Many lasers create a beam that may be approximated as a Gaussian beam; such beams have the minimum possible divergence for a given beam diameter, which makes them ideal for use in medical applications. When it comes to some high-power lasers, Hermite–Gaussian or Laguerre–Gaussian functions can be used to approximate the majority of their transverse modes in some instances. Tophat beams, which have a flat top, are occasionally employed in high-power lasers. Unstable laser resonators, which are not used in most lasers, are responsible for the production of fractal-shaped beams. Bessel beams and optical vortexes, which need specialized optical devices, can be generated.

The wavefronts of a laser beam are flat and normal to the propagation direction, and there is no beam divergence at the "waist" (or focal region) of a laser beam at its focal point. However, due to diffraction, this can only be true for a restricted range of wavelengths inside the Rayleigh range, limiting the application of this principle. As required by diffraction theory, the beam of a single transverse mode (gaussian beam) laser gradually diverges at an angle that changes inversely with the beam diameter over a long period of time. Thus, A standard helium–neon laser's "pencil beam," if directed at the Moon, would cover an area of about 500 kilometers (from the distance of the earth). While this is not the case with the light from a semiconductor laser, it often has a considerable divergence when it leaves the small crystal: up to 50° It is possible to collimate even a divergent beam with a lens system, as is the case with laser pointers that use laser diodes for their light source. As a result of the light's one-dimensional mode, this can be accomplished. This quality of laser light, spatial coherence, cannot be recreated using normal light sources (except by discarding most of the light), as can be shown by contrasting the beam from a flashlight (torch) or spotlight with the beam from practically any laser. The width, divergence, and intensity profile of laser beams can be measured with a laser beam profiler because of

the reflectivity of a laser beam off of a matte surface, a speckle pattern is formed that contains interesting properties that should be explored further.



Quantum vs. classical emission processes

Radiation is produced by a laser by the process of stimulated emission, in which energy is retained after a transition in an atom or molecule has occurred in the laser. Einstein said that this was a quantum phenomena [dubious – discuss] that took place spontaneously and could be represented by two coefficients: the A coefficient (which pertains to spontaneous emission exclusively) and the B coefficient (which is not applicable to spontaneous emission) (which applies to absorption and stimulated emission only). In the case of a free-electron laser, the atomic levels have a significant influence. In the case of the free-electron laser, it appears that the behavior of this relatively unusual technology may be explained without resorting to quantum physics.

Operation in both continuous and pulsed modes

An operating mode can remain classified as either continuous or pulsed depending on whether the output power is either constant or pulsed at various time intervals, depending on the type of laser. A laser that emits a continuous stream of light can nevertheless be used to generate pulses of light by intentionally turning it on and off at a predetermined rate. However, a "modulated" or "pulsed" continuous wave laser is defined modulation rate is slower than the lifetime and storage period of the lasing

material or pumping mechanism of the cavity; this is referred to as "slow modulation." Most laser diodes used in communications systems are classified as this type.

Continuous-wave operation

Approximately laser applications require a laser beam with a constant output power throughout time, which is provided by a continuous-wave laser. A continuous-wave laser is a name given to this type of laser (CW). In order to operate in the continuous wave mode, there are many different types of lasers that can be adapted. which will allow them to meet the criteria of this application. Due to the fact that many of these lasers are capable of lasing in multiple longitudinal modes at the same time, beats between the slightly different optical frequencies of those oscillations will in fact produce amplitude variations on time scales that are shorter than the round-trip time (the reciprocal of the frequency spacing between modes), which is typically a few nanoseconds or less in the vast majority of instances. When taken as an average across longer periods of time, these lasers are nevertheless referred to as "continuous wave" lasers because their output power remains constant, and the very high-frequency power changes have little or no effect on the intended use. (However, the term "mode-locked laser" is not used in the context of mode-locked lasers, when the goal is to generate very short pulses at the rate of the round-trip time.

A constant pump source is required to replenish the populace inversion of the gain medium for continuous-wave operation. This isn't possible in some laser mediums. As a result of the high power levels required in some other lasers, this is either not feasible or the laser will be destroyed due to its high temperature during operation. You cannot use a CW mode on these lasers.

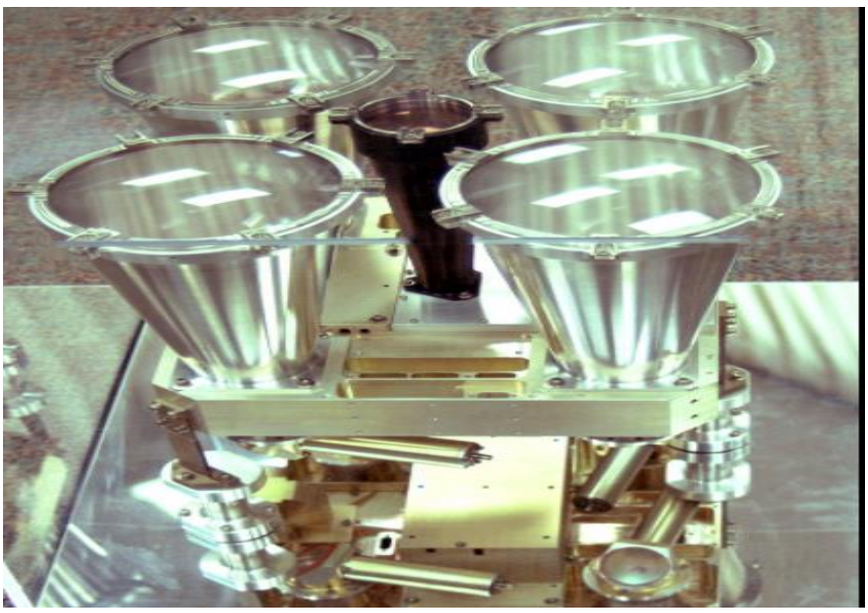
Pulse-operated machine

Pulsed operation is used to describe any laser that does not function as a continuous wave and instead produces optical power in pulses with a particular duration and repetition rate. This diverse spectrum of technologies is capable of achieving a variety of goals. Some lasers can only be operated in a pulsed mode, and as a result, this is the only mode of operation available.

In other cases, the application necessitates the generation of pulses with the highest possible energy. There are occasions when it is possible to achieve this goal simply by dropping the pulse rate so that more energy can be built up in between pulses. It is possible to evaporate a very small size of material at the work piece's surface in a short period of time using laser ablation while providing the energy gradually allows the heat to be transferred into its bulk, preventing it from ever reaching a temperature high enough to evaporate the material.

For nonlinear optical effects, peak pulse power (rather than pulse energy) is more important than pulse energy. If pulse energy is to be used, the smallest possible pulses must be generated using techniques like Q-switching.

Optical bandwidth can never be smaller than the pulse width's inverse because it would be a mathematical impossibility. In contrast to the relatively narrow bandwidths found in CW lasers, this suggests lasing over a vast bandwidth in the case of extremely short pulses. Laser pulses can be as short as a few femtoseconds (10^{-15} s) in some dye and vibronic solid-state lasers because of the high bandwidth of the lazing medium.



Q-switching

An inverted population can be built up in a Q-switched laser by increasing the loss inside the resonator, which is also known as the quality factor or 'Q.' Finally, the loss mechanism (which is commonly an electro- or acousto-optical element) is swiftly removed, allowing lasing to commence, which quickly recovers the stored energy in the gain medium, allowing the pump energy to reach its maximum level. As a result, by utilizing that energy, a short pulse with a high peak power can be formed.

Mode-locking

Mode-locked lasers can produce pulses with durations ranging from a few picoseconds to a few femtoseconds. During the time it takes light to travel between the two mirrors in the resonator, these pulses will be repeated. An extremely brief pulse has a wide spectrum because of the Fourier limit (also known as energy-time uncertainty). So the gain medium must be capable of amplifying those frequencies with a wide enough gain bandwidth. Such a material has a very wide gain bandwidth and can thus create pulses as short as a few femtoseconds in duration as titanium-doped, artificially produced sapphire (Ti: sapphire).

When examining processes that occur on extremely short time scales (such femtosecond physics, femtosecond chemistry, and ultrafast science), mode-locked

lasers are an invaluable tool for maximizing the influence of optical nonlinearity (e.g. in second-harmonic generation, parametric down-conversion, optical parametric oscillators and the like). In other words, the identical and perfectly periodic pulses of a mode-locked laser (and not just the envelopes of those pulses) are phase-coherent. Lasers with short pulses can be used in a wide range of scientific applications, not just because of their high peak strengths.

Pulsed pumping

A pulsed laser can also be achieved by using a source that is itself pulsed, either by electronic charging in the case of flashbulbs, or another pulsed laser. As a result of the short-inverted people lifetime of a dye molecule, pulsed pumping was used in dye lasers in the past. Large capacitors were charged and then discharged using flashlamps, creating an intense flash as a solution to this problem. For three-level lasers, pulsed pumping is also necessary because the lower energy level quickly becomes very crowded, prohibiting further lasing until those atoms relax to the ground state. For example, copper vapor lasers and excimer lasers can never be used in CW mode.

Laser

Graduate student Gordon Gould was researching the energy levels of excited thallium at Columbia University at the same time. As a general topic of discussion during their first meeting, Gould and Townes discussed the emission of radiation. Later that year, Gould recorded some of his ideas for a "laser" in November 1957, including the use of an open resonator and the usage of a laser diode (later an essential laser-device component). Also, in 1958, Prokhorov came up with the concept of using an open resonator, which was the first time that this concept was published in a scientific journal. While Prokhorov's writings and Gould's unpublished laser work were being studied, Schawlow and Townes made the decision to use an open-resonator laser design. After Gordon Gould delivered his article The LASER, Light Amplification by Stimulated Emission of Radiation in 1959, the acronym "LASER" first appeared in print. Three and thirteen are the numbers. Gould wanted to use several "-ASER" acronyms for other wavelengths of light, such as "XASER" for x-rays, "UVASER" for ultraviolet, and so on. In spite of the fact that "RASER" was briefly popular for identifying radio-frequency-emitting devices, "LASER" became the generic term for all non-microwave devices.

Gould's notes included a list of prospective laser uses, including spectroscopy, interferometry, radar, and nuclear fusion, among others. He proceeded to improve the concept, and in April 1959, he filed a patent application for it. In 1960, the United States Patent and Trademark Office dismissed his application and issued a patent to Bell Labs. This sparked a twenty-eight-year legal battle in which the stakes were both scientific prestige and financial gain. It was not until 1987 that Gould was awarded his first big patent litigation victory, when the United States Patent and Trademark Office was directed to issue patents to Gould for optically pumped laser devices and gas discharge laser devices, both of which were invented by Gould. Historians are still grappling with the subject of who should be given credit for creating the laser in the first place.

A head of numerous other research teams, including those of Townes at Columbia University, Arthur Schawlow at Bell Labs, and Gould at TRG (Technical Research Group), Theodore H. Maiman operated the first working laser on May 16, 1960, at Hughes Research Laboratories in Malibu, California. A flashlamp-powered synthetic ruby crystal was utilized to generate red laser light with a wavelength of 694 nanometers in Maiman's functioning laser. Due to its three-level pumping design, the gadget was only capable of pulsed operation. It wasn't until later in the year that Iranian physicist Ali Javan and colleagues William R. Bennett and Donald Herriott built the first infrared gas laser utilizing helium and neon (US Patent 3,149,290); Javan later got the Albert Einstein Award in 1993 for his work on this project. The semiconductor laser diode concept was proposed by Basov and Javan. It was in 1962 that Robert N. Hall demonstrated the first laser diode device, which was built of gallium arsenide and radiated at 850 nm.

First semiconductor laser with visible emission was shown later that year by Nick Holonyak Jr. As a pulsed-beam laser, It could only be used at temperatures below liquid nitrogen (77 K). A room-temperature, continuous-operation diode laser based on the heterojunction structure was independently developed in 1970 by Zhores Alferov, Bell Telephone Laboratories' Izuo Hayashi and Morton Panish were among those who worked on the project (BTL).

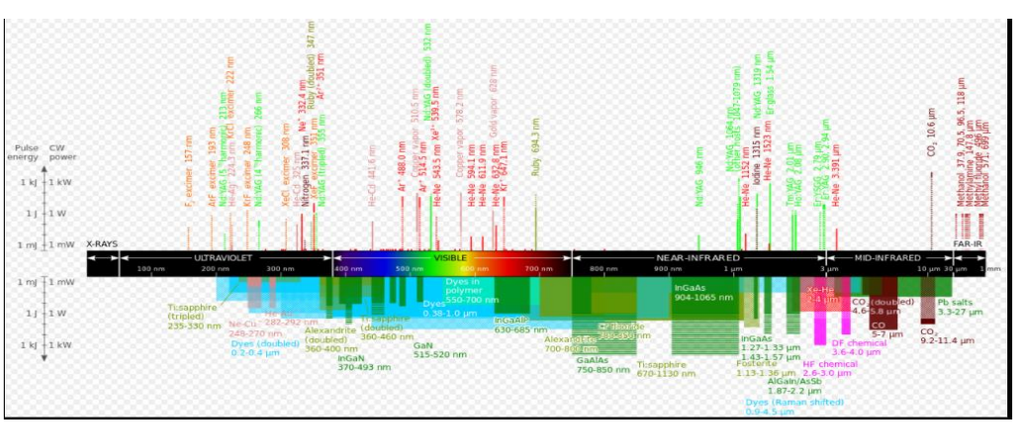
Gas Lasers

There have been numerous other gas discharges that can enhance light coherently since the HeNe gas laser was invented. Many different gases have been utilized to build gas lasers, and these lasers have been put to good use. The helium-neon laser (HeNe) can operate at a wide range of wavelengths thanks to its versatility. Many of

these low-cost, high-coherence devices are used in optical research and education because of their wide availability and low cost, commercial carbon dioxide (CO_2) lasers are capable of emitting many hundreds of watts that can be concentrated into a small area. Such thermal infrared lasers are commonly employed for cutting and welding in the industrial sector and emit at a wavelength of 10.6 m. A CO2 laser's efficiency is unusually high, at over 30%. [46] The wavelength range between 351 and 528.7 nm is covered by various transitions in argon-ion laser systems. In some cases, many of these transitions, such as those at 458 nm, 488 nm, and 514.25 nm, may be lasing at the same time, depending on how the optical design is implemented.

A nitrogen TEA laser (transverse electrical discharge in gas at atmospheric pressure) is a low-cost gas laser commonly produced by hobbyists that emits UV light at 337.1 nm that is quite incoherent. Deep ultraviolet wavelengths can be generated using metal ion lasers, which are gas lasers. HeAg (Helium Agni) and NeCu (Neon Copper) are two such materials with wavelengths in the 224- and 248-nm ranges. Fluorescence suppressed Raman spectroscopy can benefit from the narrow linewidth of low-pressure gas lasers, which have oscillation frequencies of less than 3 GHz (0.5 picometers).

Lasing without preserving a population inversion was demonstrated in 1992 with sodium gas and again in 1995 with rubidium gas by multiple multinational teams. [49] [50] By creating and destructively nosy with ground electron transitions between two routes, we were able to cancel out any potential energy absorption by the ground electrons by means of an external maser.



Chemical Lasers

Lasers powered by chemicals can rapidly emit enormous amounts of energy because of the chemical mechanism that drives them. Despite the fact that continuous wave

chemical lasers with extremely high power levels, powered by streams of gasses, have been produced and can be employed in some industrial applications, this technology is primarily of interest to the military. A couple of examples are the hydrogen fluoride laser (2700–2900 nm) and the deuterium fluoride laser (3800 nm), which both use hydrogen or deuterium gas in combination with ethylene combustion products in nitrogen trifluoride to produce a laser beam.

Excimer lasers

Excimer lasers use an excimer, or more accurately an exciplex, as the lasing medium and are driven by an electric discharge. Only one atom in an exciting electrical state can form these molecules. The molecule disintegrates when the excitation energy of the molecule is transferred to a photon. Population inversion is made easier by a reduction in the lower energy state's population. There are now only noble gas compounds being employed as excimers, and noble gasses are chemically inert. LASIK eye surgery and semiconductor photolithography are two of the most common uses of excimer lasers.

Examples of commonly used excimer molecules are ArF (193-nm emission), KrCl (222- and 248-nm emission), and XeCl and XeF (at 308-nm and 244-nm, respectively) (351 nm). In the vacuum ultraviolet, the molecular fluorine laser, which has an emission wavelength of 157 nm, is commonly referred to as an excimer laser. There is a problem with this, though, because F2 is a stable compound.

Lasers solid state

A 50 W FASOR, based on a Nd:YAG laser, used at the Starfire Optical Range

Solid-state lasers require ions to be "doped" into a crystal or glass rod. For instance, the first operational laser was a ruby laser, which was composed of ruby (chromium-doped corundum). The dopant actually maintains the population inversion. A flash tube or another laser may be used to pump these materials optically at a lower wavelength than the lasing wavelength. Although the phrase "solid-state" can be used broadly, it is used in laser physics in a more specific context. For the sake of this discussion, solid-state lasers relate to semiconductor lasers (e.g., laser diodes).

These include Nd:YVO4, Nd:YLF, and Nd:AAG solid-state laser crystals, as well as neodymium orthovanadate and yttrium lithium fluoride (Nd:YLF) (Nd:YAG). They can all produce enormous amounts of infrared power at a wavelength of 1064 nm. In addition to being used for cutting or welding metals, they can also be utilized for spectroscopy and pumping dye lasers, as well as being used for spectroscopy. It is

possible to generate beams of 532 nm (green, visible), 355 nm (blue) or 266 nm (infrared) (ultraviolet). With DPSS (frequency-doubled diode-pumped solid-state) lasers, bright green laser pointers can be generated.

It is also popular in solid-state lasers to use "dopants" like ytterbium, thulium, and erbium. [52] It is found in crystals such as Yb: CaF2 and CaF2: KGW, Yb: KGW, Yb: KYW, and BOYS, among other things. Wavelengths between 1020 and 1050 nanometers are often used in this application. It is possible that they will be very efficient and powerful due to the occurrence of a tiny quantum fault. The use of Yb: YAG allows for the generation of extraordinarily high powers in ultrashort bursts of light. The holmium-doped YAG crystals emit at a wavelength of 2097 nm, resulting in a highly efficient laser that can penetrate water-rich tissue. With the aid of optical fiber surgical instruments, the Ho-YAG may be used in a pulsed mode to treat joints that have been damaged by arthritis or teeth that have been decayed by rotten pulp.

The infrared laser produced by titanium-doped sapphire (Ti: sapphire) is extensively employed in spectroscopy because of its high level of tunable tuning. Additionally, it is well known for its use as a mode-locked laser that produces ultrashort pulses with exceptionally high peak powers.

Unconverted pump power warms the medium in solid-state lasers, causing thermal limits. If the thermo-optic coefficient (dn/dT) is high, the heat can source thermal lensing and impair the quantum efficiency of a laser system. Diode-pumped thin-disk lasers circumvent these challenges by using a gain medium that is much narrower than the width of the pump beam. An even distribution of heat throughout the material is achieved as a result of this method. Laser beams up to one kilowatt have been demonstrated using thin disk devices.

Fiber lasers

Fiber lasers are solid-state lasers or laser amplifiers that are guided by total internal reflection in a single-mode fiber and are used in a variety of applications. In fiber optics, a high surface area to volume ratio allows for efficient cooling, which is made possible by the lengthy gain areas that can be generated through light direction. Another advantage of optoelectronic fiber is that it has a low heat distortion rate, which is beneficial in some applications. Ion lasers based on erbium and ytterbium are widely used.

Quite generally, the fiber laser is designed as a double-clad fiber to save on cost. This fiber is made up of three layers: a core, an inner cladding, and an outer cladding, all of which are linked to one another. In order to take advantage of the highly multimode core of the outer cladding, the index of the three concentric layers is selected in such a way that the fiber core behaves as though it were a single-mode fiber for laser emission. The use of a large numerical aperture (NA) allows for the injection and transmission of huge amounts of power into and through the active inner core region while retaining a high-power density. Pump light canister remain used more efficiently by creating a fiber disk laser, or a stack of such lasers.

There is a fundamental constraint on the operation of fiber lasers in that the intensity of light in the fiber cannot be so high that optical nonlinearities caused by the local electric field strength become dominant and prevent the laser from operating or cause the fiber to be destroyed by its own laser beam. The word "photodarkening" is used to

characterize this particular phenomenon. Because of the inefficiency of the cooling system in bulk laser materials, it is difficult to discriminate between the effects of photodarkening and thermal effects. However, experiments in fibers have demonstrated that the photodarkening can be attributed to the establishment of long-living color centers.

Photonic crystal lasers

When a photonic crystal laser operates, the mode detention and density of optical states (DOS) structure required for feedback are provided by the nanostructures that form the laser's structure. They are typical micrometer-sized and tunable on the bands of the photonic crystals.

Semiconductor lasers

A 5.6 mm 'closed can' commercial laser diode, such as those used in a CD or DVD player. A semiconductor laser is a diode that is pumped with electricity. The optical gain is produced by the recombination of electrons and holes that occurs as a result of the applied current. Although in some configurations, the optical resonator can be located outside of the semiconductor device, in others, the resonator can be located within it.

From 375 to 3500 nm, commercial laser diodes can be found. Laser sticks, Laser printers, CD/DVD players, and other similar devices that make use of low- to medium-power laser diodes are all instances of such equipment. Because of their high efficacy as optical pumps, laser diodes are frequently utilized in this capacity. Diodes with output powers up to 20 kW are used in industry for cutting and welding purposes. The semiconductor active medium of external-cavity semiconductor lasers is enclosed within a larger cavity. These devices are capable of delivering high power outputs with excellent beam quality, wavelength-tunable narrow-linewidth radiation, or ultrashort laser pulses.

In 2012, Nichia and OSRAM developed and manufactured commercial high-power green laser diodes (515/520 nm), which compete by traditional diode-pumped solid-state lasers.

It is possible to make vertical-cavity surface-emitting lasers (VCSELs) by using semiconductor lasers that emit light in a path parallel to the wafer surface. In comparison to traditional laser diodes, VCSELs often produce a more circular laser beam. There are currently no commercially available VCSELs in the 850 nm wavelength range, with 1300 nm VCSELs in development, and 1550 nm devices

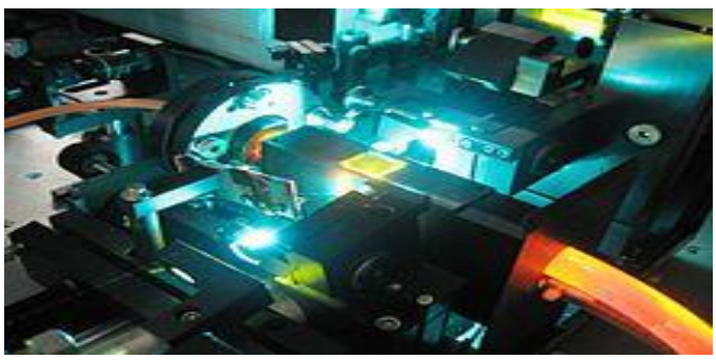
under investigation. External-cavity VCSELs are known as VECSELs. In quantum cascade lasers, electrons in a system having numerous quantum wells are able to transition between different energy sub-bands of the electron.

It is essential for optical computing to have a silicon laser developed. Because silicon is the chosen material for integrated circuits, electronic and silicon photonic components (such as optical interconnects) can be built on the same chip. Because of its lasing-preventing properties, silica is difficult to work with. Teams of scientists have recently constructed silicon lasers by manufacturing the lasing material out of silicon and other semiconducting materials, such as indium (III) phosphide or gallium (III) arsenide, materials that let silicon produce coherent light. Known as "hybrid silicon lasers," this is a new type of laser. It has also been demonstrated recently that nanowire lasers can be embedded directly onto silicon for chip-level applications. For on-chip processing of optical signals, heterostructure nanowire lasers can emit two phase-locked picosecond pulses with a repetition frequency of up to 200 GHz. Another option is a Raman laser, which generates a laser from materials such as silicon by using Raman scattering to generate the laser.

Dye lasers Dye lasers

The gain medium should be an organic dye. These lasers can be very tunable because of the large range of dyes or mixes of dyes that are available (the time span is on the order of a few femtoseconds). However, researchers have also constructed narrow-linewidth tunable emission in dispersive oscillator topologies with solid-state dye gain medium, which is a variation on the liquid form of these tunable lasers.

Solid-state dye lasers rely on dye-doped polymers to serve as the laser medium in the vast majority of cases.



Free-electron lasers

The free-electron laser FELIX at the FOM Institute for Plasma Physics Rijnhuizen, Nieuwegein. Infrared, visible, and soft X-ray wavelengths can all be generated using free-electron lasers (also known as FELs). When compared to other types of lasers, these lasers have the broadest frequency range. Despite the fact that FEL beams share the same optical properties as other lasers (such as coherent radiation), the way in which they operate is fundamentally different from one another. Free-electron lasers (FELs) are so named because they utilise a relativistic electron beam as their lasing medium.

Exotic media

Since the early 1970s, academics have been working to develop a high-quantum-energy laser that utilizes transitions between isomeric states of an atomic nucleus. Three review pieces sum up a lot of what we learned. This study is transnational in scope but mostly based in the United States and the former Soviet Union. While many experts believe a breakthrough is imminent, a working gamma-ray laser has yet to be achieved.

Early studies focused on using short neutron pulses to excite a solid's top isomer state, in order to make use of the Mössbauer effect's line-narrowing for gamma-ray transitions. When utilized in conjunction with a three-level system, it was expected that the two-stage pumping would provide a number of advantages. An atom's nucleus may experience a stronger dipole field from a coherently oscillating electron cloud powered by a laser than from the driving laser. Additionally, the oscillating cloud's nonlinearity would produce both spatial and temporal harmonics, allowing higher multipolarity nuclear transitions to be induced at frequencies multiplied by the laser.

According to a BBC article from September 2007, positronium annihilation could be used to power an extremely strong gamma-ray laser. According to Dr. David Cassidy at the University of California, Riverside, an inertial confinement fusion experiment could eliminate the need for hundreds of lasers by using just one of these types of lasers instead.

Space-based X-ray lasers pumped by a nuclear explosion have too been proposed as antimissile weapons. Such devices would be one-shot weapons.

Laser light has been produced by living cells. A green fluorescent protein was genetically inserted into the cells (GFP). As the laser's "gain medium," the GFP is utilized to enhance the light. A "laser cavity" was created by placing the cells between two small mirrors, each just 20 millionths of a meter across, that allowed light to bounce through the cell numerous times. After exposing the cell to blue light, it began emitting a green laser light that was focused and bright.

Natural lasers

A natural laser can be created by irradiated planetary or stellar gases, just like astrophysical masers. The phenomenon is visible on Mars, Venus, and MWC 349.

A solution in search of an issue was how lasers were first described in 1960. As a result, they've spread throughout the modern world, appearing in a plethora of fields ranging from consumer electronics and information technology to research, medicine, and industry, as well as in government, law enforcement, the arts, and the military. The Internet and other modern communication services are made possible by fiber-optic transmission, which uses lasers to transmit data.

In 1974, the supermarket barcode scanner became the first widely visible application of lasers. However, it wasn't until 1982 that laser-equipped CD players and printers became commonplace, making laser-disc players the first successful consumer product to include a laser.

Some other uses are:

Communications: lasers, in addition to fiber-optic transmission, are utilized for free-space optical communication, which includes laser communication in space, among other applications.

Typical applications in industry include laser cutting, laser welding, laser heat treatment, laser marking (engraving and bonding), additive manufacturing or 3D printing procedures such as laser sintering and selective laser melting, non-contact measurement of parts as well as 3D scanning, and laser cleaning

The military can utilize electronic countermeasures (EOCM) and lidar to locate targets, guide missiles, guard against missile defense systems, and even blind soldiers. For more information, please see the following.

Legal action: Traffic enforcement with LIDARs. When it comes to forensic fingerprinting, lasers are an essential tool.

Research: spectroscopy, laser ablation, laser annealing, laser scattering, lidar, laser capture microdissection, fluorescence microscopy, metrology, and laser cooling.

Laser printers, barcode scanners, thermometers, laser pointers, holograms, and bubblegrams are some examples of commercial items.

When diode lasers are excluded, a total of 131,000 lasers were sold in 2004 for a total value of $2.19 billion dollars. In 2007, more than a billion diode lasers were sold for a total of $3.20 billion.

In medicine

The following are the most relevant articles: Medical Lasers and Lasers for Cancer Treatment. In addition to cosmetic skin treatments such as acne treatment, cellulite reduction and striae reduction as well as hair removal, laser surgery (particularly eye surgery), laser healing, kidney stone treatment, and ophthalmoscopy are also available in this field.

When it comes to cancer treatment, lasers are utilized to reduce or eliminate tumors or precancerous growths. Their primary application is to treat superficial malignancies that are located on or near the surface of the body, as well as malignancies that have developed in the inner lining of internal organs. These drugs are used to treat a variety of illnesses, including basal cell skin cancer, the early stages of various malignancies, such as cervical, penile, and vaginal cancers, as well as non-small cell lung cancer. Today, the use of laser therapy in conjunction with other treatments such as surgery, chemotherapy, or radiation is quite widespread. Laser-induced interstitial thermotherapy (LITT) or interstitial laser photocoagulation (ILP) is a technique for shrinking tumors by damaging or killing cancer cells. There is less damage, less discomfort, less bleeding, less swelling, and fewer scars with laser surgery than with more conventional surgical procedures of cutting and

stitching. A disadvantage is that surgeons must undergo specialized training in order to practice. Is it going to cost more than other treatments.

A potential threat was recognized even before the first laser was created. According to Theodore Maiman, the first laser was analogous to a Gillette razor blade since it was capable of burning through a Gillette blade without damaging the laser. Few milliwatt-power lasers are now universally believed to be hazardous to human vision, whether the beam strikes directly or after reflecting off a bright surface, such as a mirror, according to current consensus. The eye's ability to concentrate laser light into an extremely small patch of the retina can cause localized burning and irreparable damage in seconds or even less time, thanks to the coherence and low divergence of the laser light.

Lasers are typically branded with a safety class number, which indicates how harmful the laser is. Examples of safety class numbers include:

Class 1 is intrinsically safe, mainly because the light is confined within an enclosure, as in CD players, and hence cannot cause harm.

Class 2 is completely safe when used as intended; the blink reflex of the eye will prevent any injury. Laser pointers, for example, typically have a power of up to 1 mW.

In most cases, Class 3R (previously IIIa) lasers are up to 5 mW in power, and they pose a modest risk of eye damage when used during the blink reflex period. It is possible to inflict damage to a place on the retina by staring into such a beam for several seconds at a time.

When exposed to Class 3B, the eyes can suffer immediate injury.

Class 4 lasers can cause skin burns, and in some situations, even scattered light can cause eye and/or skin damage.

Indicated laser powers are for visible light, continuous-wave lasers, not pulsed. Power restrictions for pulsed lasers and infrared wavelengths are different. Safety goggles that absorb light of a specific wavelength are available for use by those who deal with class 3B and class 4 lasers.

The corneal absorption of infrared lasers with wavelengths longer than 1.4 micrometers is termed "eye-safe" since it does not cause damage to the retina. In reality, the term "eye-safe" might be misleading because it only refers to continuous wave beams of relatively low power; a high power or Q-switched laser at these wavelengths can burn the cornea, resulting in severe eye injury, and even moderate power lasers can cause injury to the eye.

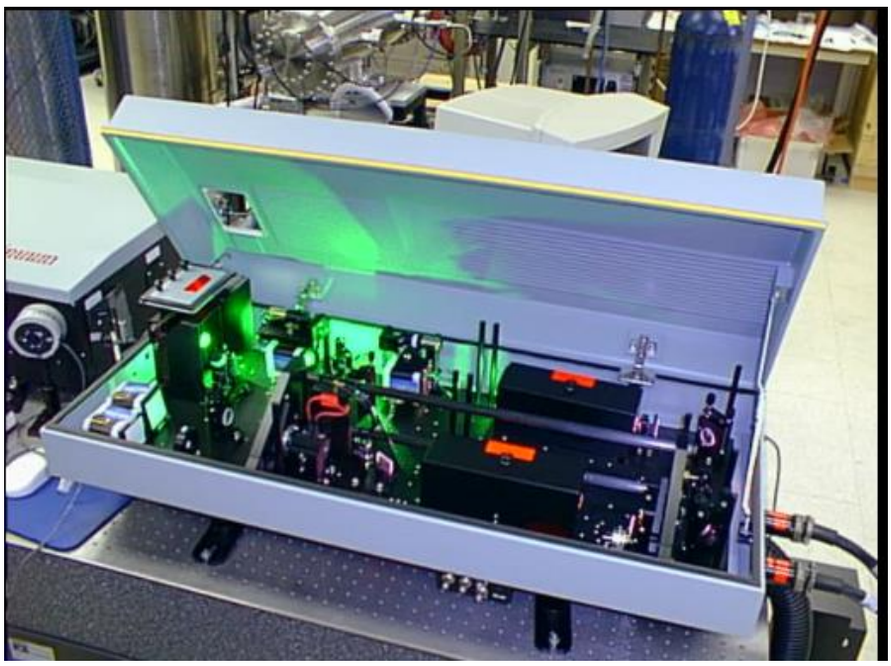
Lasers pose a threat to both civilian and military aviation since they can momentarily incapacitate or even blind pilots. For further information, check to see Lasers and Aviation Safety.

Charge-coupled device cameras may be more sensitive to laser damage than biological eyes.

Nd: YAG Laser

Nd:YAG (Neodymium –doped Yttrium Aluminum Garnet: Nd:Y3A15O12 is a laser lasing medium crystal used in solid-state lasers. Due to their similar sizes, the dopant, triply ionized neodymium, Nd (III), often replaces a tiny percentage (1%) of the YAG ions in the host crystal structure as the Yttrium ions. To a similar degree as red chromium does in ruby lasers, it is the neodymium ion that provides lasing activity in the crystal.

Laser operation of Nd: YAG was first demonstrated by J.E. Geusic et al. at Bell Laboratories in 1964.

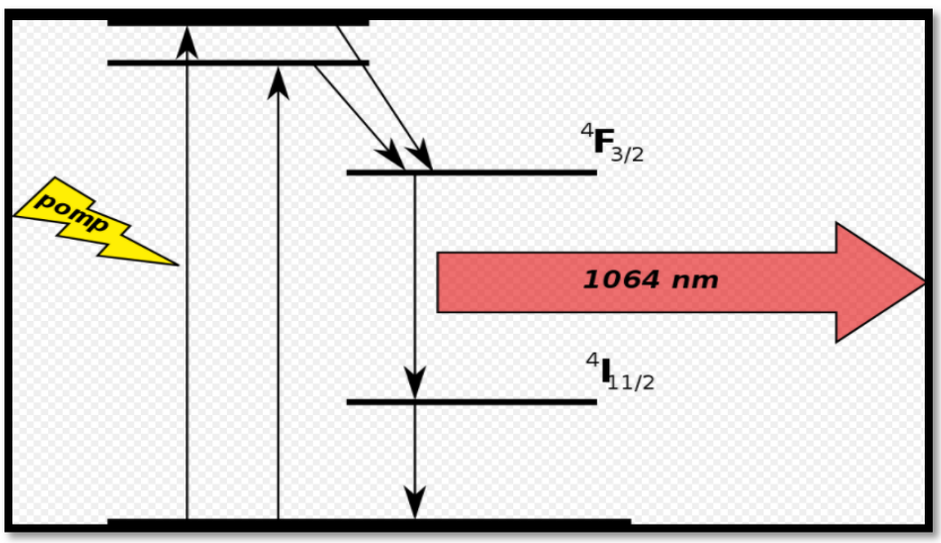


Nd:YAG lasers are optically pumped using a flash tube or laser diodes. These are one of the most common types of laser and are used for many different applications. Nd: YAG lasers typically emit light with a wavelength of 1064 nm, in the infrared. However, there are also transitions near 946, 1120, 1320, and 1440 nm. Nd: YAG lasers operate in both pulsed and continuous modes. Pulsed Nd: YAG lasers are typically operated in the so-called Q-switching mode: An optical switch is inserted in the laser cavity waiting for a maximum population inversion in the neodymium ions before it opens. Then the light wave can run through the cavity, depopulating the excited laser medium at maximum population inversion. In this Q-switched mode, output powers of 250 megawatts and pulse durations of 10 to 25 nanoseconds have been achieved. The high-intensity pulses may be efficiently frequency-doubled to generate laser light at 532 nm, or higher harmonics at 355, 266, and 213 nm.

Nd: YAG mostly absorbs in the 730–760 nm and 790–820 nm ranges, respectively. Low current density krypton flashlamps create more light in those wavelengths than xenon lamps, which produce more light at 900 nm. As a result, pumping with the former is more efficient. Light-emitting diode (LED) lasers.

The amount of neodymium dopant in the material depends on the application. In contrast to pulsed lasers, the doping level required for continuous-wave output is far less intense. Lightly doped CW rods appear practically white to the naked eye, whereas higher-doped rods appear pinkish-purple to the naked eye.

Other common host materials for neodymium are: YLF (yttrium lithium fluoride, 1047 and 1053 nm), YVO4 (yttrium orthovanadate, 1064 nm), and glass. A particular host material is chosen in order to obtain the desired combination of optical, mechanical, and thermal properties. Nd: YAG lasers and variants are pumped either by flash tubes, continuous gas discharge lamps, or near-infrared laser diodes (DPSS lasers). Prestabilized laser (PSL) types of Nd: YAG lasers have proved to be particularly useful in providing the main beams for gravitational wave interferometers such as LIGO, VIRGO, GEO600, and TAMA.



Nd: YAG lasers are used in ophthalmology to correct posterior capsular opacification, after cataract surgery, for peripheral iridotomy in patients with chronic and acute angle-closure glaucoma where it has largely superseded surgical iridectomy for the treatment of vitreous eye floaters for pan-retinal photocoagulation in the treatment of proliferative diabetic retinopathy and to damage the retina in ophthalmology animal research.

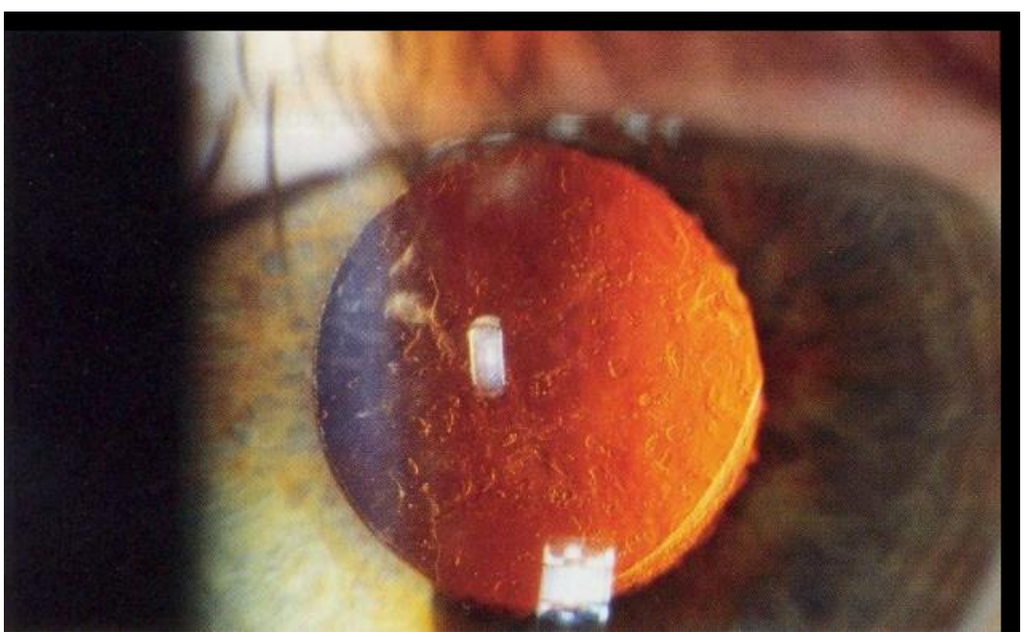
Laser-induced thermotherapy, in which benign or malignant tumors in various organs are ablated by a beam of light from a Nd: YAG laser, is the most common application for this wavelength of light.

In oncology, Nd: YAG lasers can be used to remove skin cancers. They are also used to reduce benign thyroid nodules and to destroy primary and secondary malignant liver lesions.

Nd:YAG lasers can be used for laser prostate surgery, which is a type of transurethral resection of the prostate.

Laser hair removal and the treatment of minor vascular flaws like spider veins on the face and legs are both common uses for these lasers in aesthetic medicine as well. A laser called an Nd: YAG can also be used to treat Venous Lake lip lesions. Recently, Nd: YAG lasers have been utilized to treat dissecting cellulitis of the scalp, an uncommon skin disease. Using hysteroscopy the Nd: YAG laser has been used for the removal of uterine septa within the inside of the uterus.

Nail fungus infection (onychomycosis) is treated with a Nd:YAG laser in podiatric medicine. It's not yet apparent whether laser treatment for these infections has any benefits, but research is being conducted to find out whether it does.



Dentistry

The use of Nd:YAG dental lasers for the eradication of dental caries has been demonstrated as an alternative to drilling therapy, despite the low quality of the evidence supporting this use.1 Soft tissue procedures in the oral cavity, such as gingivectomy, periodontal sulcular debridement, LANAP [29] and pulpotomy have also been performed with these instruments. As an addition to periodontal instrumentation and for the treatment of recurrent aphthous stomatitis, Nd: YAG dental lasers have also been demonstrated to be useful in the treatment and prevention of tooth hypersensitivity.

Manufacturing

When it comes to metal surface improvement techniques like laser peening, Nd: YAG lasers are used for engraving, etching, or marking a variety of metals and plastics. Steel, semiconductors, and other alloys are just a few of the materials they cut and weld with regularity throughout the manufacturing process. The average power levels for automotive applications (such as cutting and welding steel) are between 1 and 5 kW. Pulsed Nd: YAG lasers are commonly used for superalloy drilling (on gas turbine parts) (millisecond pulses, not Q-switched). Additionally, Nd: YAG lasers can also be used to create subsurface marks in transparent materials like glass and acrylic glass. To melt metals selectively, high-power lasers of up to 2 kW are employed. Airflow and heat exhaust efficiency can be improved by drilling cooling holes with this type of tool in aeronautical applications. Nd: YAG lasers are also applied in the non-conventional rapid prototyping procedure laser engineered net shaping (LENS).

When using high energy (10 to 40 Joule), 10 to 30 millisecond pulse, flashed laser systems to generate gigawatts of power by focusing the laser beam to a few millimeters in diameter, laser peening can be used to create extremely high-power lasers. Because it does not heat or add material, laser peening is distinct from other manufacturing processes. It is a mechanical technique of cold manipulating the metal component to create compressive residual stresses. Component damage tolerance and fatigue life and strength are improved by laser peening in gas-fired turbine engines in both aerospace and power generating.

Fluid dynamics

Using Nd: YAG lasers, fluid dynamics visualization techniques can be conducted (For example, particle image velocimetry or laser-induced fluorescence are both types of imaging techniques.).

Biophysics

Nd: YAG lasers are commonly utilized to produce biological optical tweezers. Because Nd: YAG lasers typically emit at a wavelength of 1064 nm, this is the primary reason. A low absorption coefficient for biological samples at this wavelength is due to the fact that biological samples are often composed of water. As

a result, the use of an Nd: YAG laser minimizes the harm to the biological material that is being investigated.

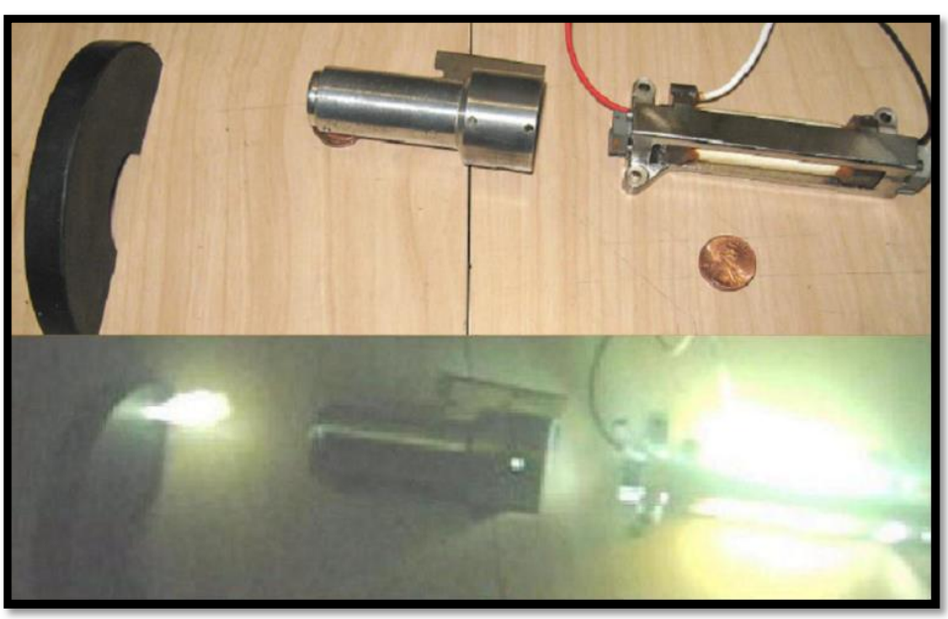
Automotive

National Institutes of Natural Sciences (NINS) researchers in Japan are working on laser igniters that will employ YAG chips to ignite fuel in an engine, rather than a spark plug. The lasers ignite the fuel with a series of 800 picosecond long pulses, resulting in a speedier and more uniform ignition. These kinds of igniters, according to the researchers, could result in improved performance and fuel economy, as well as lower levels of harmful emissions.

Military

The Nd:YAG laser is the most common laser used in laser designators and laser rangefinders. More than 4,000 Iranian soldiers suffered laser eye injuries during the Iran-Iraq war as a result of lasers from Iraqi sources ranging from tank rangefinders to anti-aircraft guns. Initially, Nd:1064 YAG's nm wavelength is regarded to be particularly harmful because it is undetectable and does not cause any discomfort.

Due to their restriction by the Convention on Certain Conventional Weapons, only 22 of the Chinese ZM-87's blinding laser weapons have been created. In 2003, North Korea is said to have used one of these weapons against U.S. military helicopters.



Cavity ring-down spectroscopy (CRDS)

Cavity ring-down spectroscopy, which measures the concentration of a light-absorbing material, can make use of the Nd: YAG.

Laser-induced breakdown spectroscopy (LIBS)

In the examination of elements in the periodic table, a variety of Nd: YAG lasers are utilized. In comparison to conventional methods such as XRF or ICP, the application itself is relatively new. However, it has shown to be a less time-consuming and more cost-effective means of determining element concentrations. In order to generate plasma, a high-power Nd: YAG laser is directed onto the sample surface. It is possible to identify each element's characteristic spectra using spectrometers since light from the plasma is collected by them. This allows the amounts of elements in a sample to be determined.

Laser pumping

The second and third harmonics of Nd: YAG lasers are widely used to excite dye lasers, which can be either in liquid or solid form. They can also be used to pump vibronically broadened solid-state lasers such as Cr4+:YAG or Ti: sapphire lasers via the second harmonic.

Additional frequencies

Nonlinear optical materials such as lithium triborate, which have a visible (532 nm, green) or ultraviolet wavelength, can be used to increase the frequency of infrared light for a variety of purposes. The 4th and 5th harmonics of the Nd: YAG 1064 nm fundamental wavelength are generated by cesium lithium borate. Green laser pointers are Nd: YVO4 diode-pumped solid-state lasers with a frequency-doubling diode (DPSS laser). The non-principal wavelength of Nd: YAG can likewise be made to emit light. In "blue laser pointer" DPSS lasers, the line at 946 nm is commonly doubled to 473 n.

Physical and chemical properties of Nd:YAG

Properties of YAG crystal

Formula: $Y_3Al_5O_{12}$

Molecular weight: 596.7

Crystal structure: Cubic

Hardness: 8–8.5 (Mohs)[51]

Melting point: 1970 °C (3540 °F)

Density: 4.55 g/cm^3

Refractive index of Nd: YAG [edit]

Wavelength (μm)	Index n (25 °C)
0.8	1.8245
0.9	1.8222
1.0	1.8197
1.2	1.8152
1.4	1.8121
1.5	1.8121

Properties of Nd:YAG @ 25 °C (with 1% Nd doping)[edit]

Formula: $Y_{2.97}Nd_{0.03}Al_5O_{12}$

Weight of Nd: 0.725%

Atoms of Nd per unit volume: 1.38×1020 /cm3

Charge state of Nd: 3+

Emission wavelength: 1064 nm

Transition: $^4F_{3/2} \rightarrow {}^4I1_{1/2}$

Duration of fluorescence: 230 μs[51]

Thermal conductivity: 0.14 $W \cdot cm^{-1} \cdot K^{-1}$

Specific heat capacity: 0.59 $J \cdot g^{-1} \cdot K^{-1}$

Thermal expansion: 6.9×10^{-6} K^{-1}

dn/dT: 7.3×10^{-6} K^{-1}

Young's modulus: 3.17×10^4 $K \cdot g/mm^{-2}$

Poisson's ratio: 0.25

Resistance to thermal shock: 790 $W \cdot m^{-1}$.

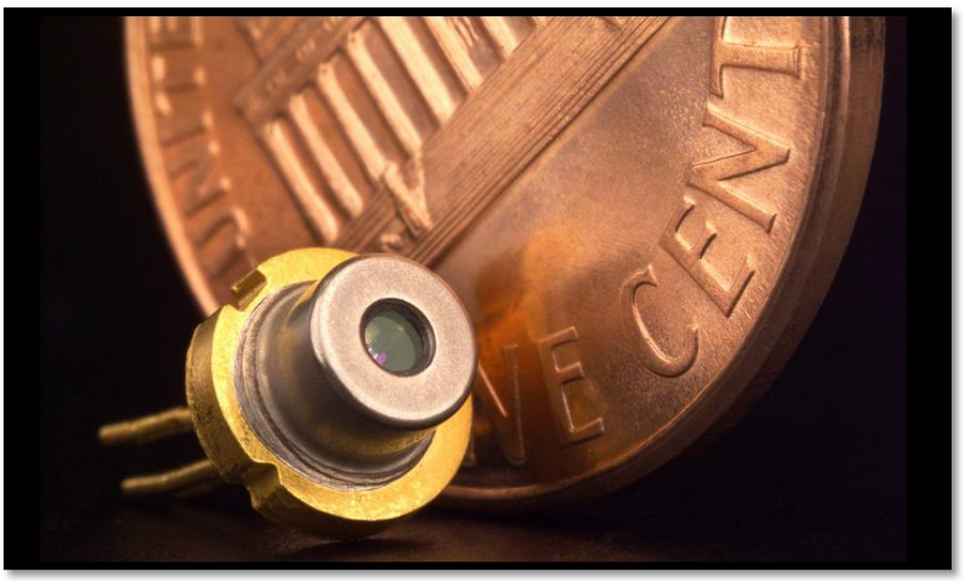
Semiconductor laser

There are several other names for this semiconductor device, but they all refer to a light-emitting diode that can be made to produce lasing conditions at the junction of the diode by pumping current into the diode. Using a laser diode, an electrical source can be converted directly to light. The doped p-n-transition, which is activated by voltage, enables electron-hole recombination.

A photon is emitted when an electron falls in energy from a higher to a lower level. This causes radiation. This is spontaneous emission. Light with the same phase coherence and wavelength can be stimulated if the process is prolonged and generates more light with the same properties.

Today's laser diodes emit a spectrum of wavelengths ranging from the infrared to the ultraviolet spectrum, depending on the semiconductor material used. One of the most common types of lasers is the laser diode, which has a wide range of applications, such as fiber optic networking, barcode readers, and laser pointers, as well as reading and recording CD, DVD, and Blu-ray disks, laser printing, and laser

scanning. Laser diodes can be used for general illumination by incorporating a phosphor, similar to that found in white LEDs.



Theory of operation of simple diode

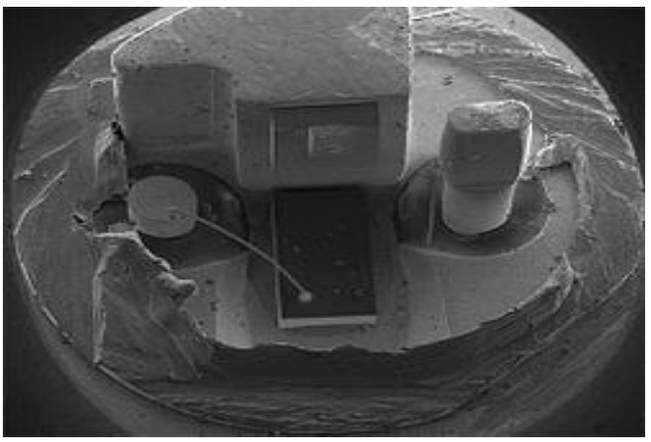
A laser diode is a PIN diode in the electrical sense. Carriers (electrons and holes) are pumped into the intrinsic (I) region of the laser diode, which is where the laser diode's active region is located. Modern lasers use the double hetero-structure implementation, where the carriers and photons are restricted in order to increase the chances of their recombination and light generation. Initially, diode laser research was conducted on basic P-N diodes. A laser diode's purpose is to recombine all the carriers in the I region and produce light, unlike a conventional diode. Thus, direct band-gap semiconductors are used to manufacture laser diodes. One of the crystal growth processes is used to construct the epitaxial structure, starting with an N doped substrate and growing the I doped active layer, followed by the P doped cladding and the contact layer. Quant wells are commonly used in the active layer because they lower the threshold current and increase efficiency.

op: a scale model of a packed laser diode. Using a needle as a scale, the laser diode chip is removed from its packaging and put on the eye.

Electrical and optical pumping

These semiconductor p-n junction diodes are subdivided into laser diodes and n-channel diodes. Due to the laser diode's forward electrical bias, the two types of charge carriers — holes and electrons — are "injected" into the depletion area from opposing sides of the p-n junction. The p-doped, and the n-doped, semiconductors inject holes and electrons into each other. ("Depletion regions," which are regions in which no charge carriers are present, arise when n- and p-type semiconductors come into contact with each other) Diode lasers are sometimes referred to as "injection lasers" or "injection laser diodes" because of their use of charge injection to fuel their operation (ILD). Because they are semiconductor devices, diode lasers can be referred to as semiconductor lasers as well. Diode lasers are distinguished from solid-state lasers by any of the following labels: diode lasers or solid-state lasers.

Optical pumping can also be used to power some diode lasers. The pump source for optomechanically pumped semiconductor lasers is provided by another laser (often another diode laser) (OPSL). OPSL technology has a number of advantages over ILDs. In addition, the absence of interference from internal electrode structures allows for a greater variety of wavelengths to be used. If the output power ratio is tenfold, the beam parameters - divergence, shape, and direction - remain constant even when the pump power (and hence the output power) varies.



Generation of spontaneous emission

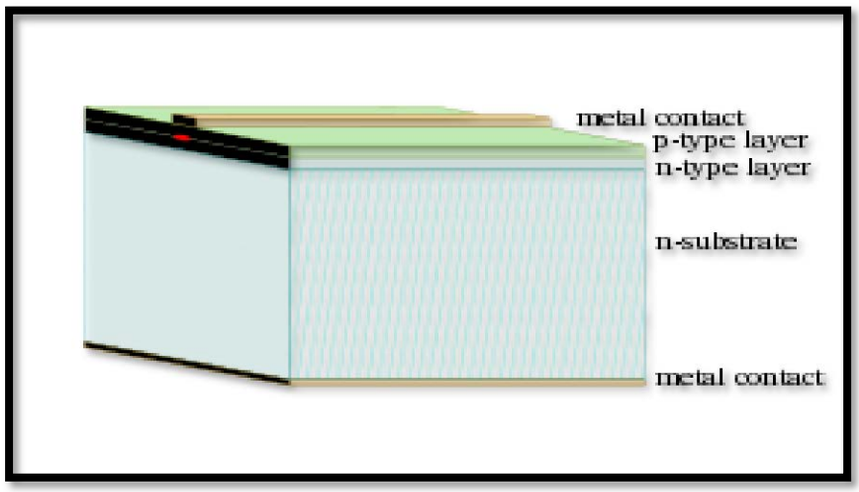
It's possible for an electron and a hole to recombine or "annihilate," resulting in an emission of energy equal to the energy difference between their original states, leading to a spontaneous emission. This is known as electron-hole recombination. Recombination of electrons and holes releases energy in the form of lattice vibrations rather than photons in a standard semiconductor junction diode. Spontaneous emission below the lasing threshold has characteristics comparable to those of an LED. Laser oscillation cannot begin without spontaneous emission, but this is only one of various inefficiencies that might arise once the laser has begun to cycle.

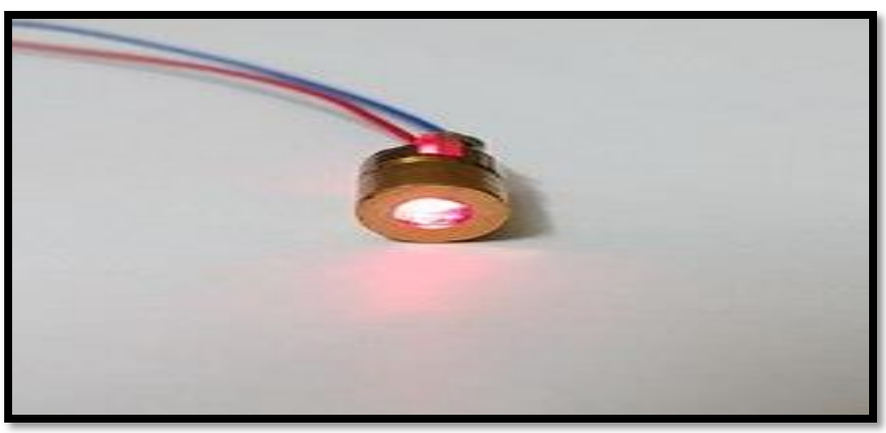
Direct and indirect bandgap semiconductors

The photon-emitting semiconductor laser differs from conventional phonon-emitting (non-light-emitting) semiconductor junction diodes in that it uses a semiconductor with a physical and atomic structure that allows for photon emission. This type of semiconductor is known as a "direct bandgap" semiconductor. Single-element semiconductors silicon and germanium have bandgaps that do not align in a way necessary to allow photon emission and therefore are not considered "direct." Other materials, the so-called compound semiconductors, have nearly identical crystalline structures to silicon or germanium but use alternating arrangements of two different atomic species in a checkerboard pattern to break the symmetry. The critical "direct bandgap" property is created by the alternating pattern's transition between materials. compound semiconductor materials like gallium arsenide, indium phosphide, gallium antimonide, and gallium nitride can all be used to make junction diodes that emit light.

Generation of stimulated emission

Electrons and holes can coexist in close proximity to one another in the absence of stimulated emission (for example, lasing) conditions for a period of time known as the "upper-state lifetime" or "recombination time," during which they do not recombine. In the case of conventional diode laser materials, this length of time is around one nanosecond. Through stimulated emission, a nearby photon with energy equal to the recombination energy can trigger recombination by interacting with it and emitting it. A second photon with the same frequency, polarization, and phase as the first photon is generated and moves in the same direction as the first. The gain in an optical wave (of the correct wavelength) caused by stimulated emission will increase as more electrons and holes are injected across the junction, which means that the number of electrons and holes injected across the junction will grow as well. Due to the fact that spontaneous and stimulated emission processes are substantially more effective in direct bandgap semiconductors than in indirect bandgap semiconductors, silicon is not a commonly used material in laser diodes.





Optical cavity and laser modes

To create a laser, an optical cavity surrounds the gain region, as it does in other lasers. When a laser diode is formed, an optical waveguide is made on the crystal's surface, resulting in a narrow beam of light. A Fabry–Pérot resonator is a crystal with absolutely smooth, parallel edges cut from both ends. Each end face of the waveguide will reflect a photon numerous times before the photon exits the waveguide. During the passage of a light wave through the cavity, the light is enhanced by stimulated emission, but some light is also lost due to absorption and incomplete reflection from the hollow's ends. Finally, if there is more amplification than loss, the diode begins to "lase". The geometry of the optical cavity has a significant impact on the performance of laser diodes. A single optical mode perpendicular to the layers is supported by most structures since light is often contained within a very thin layer. The term "multi-mode" refers to a laser that can operate in numerous transverse optical modes due to the waveguide's width in relation to the light's wavelength. This form of transversely multi-mode laser is suitable for applications requiring a great amount of

power but also does not require the TEM00 beam to be tiny enough to be diffraction-limited, such as printing, activating chemicals, microscopy, or pumping other laser types.

When a narrow beam is required, the waveguide must be constructed as narrow as the wavelength of the light. As a result, a diffraction-limited beam can only be generated in one transverse mode. Laser pointers, optical storage, and fiber optics all make use of single spatial mode devices. Keep in mind that these lasers may still support several longitudinal modes and hence lase at different wavelengths at the same time, which is significant. The emission wavelength is determined by the bandgap of the semiconductor material as well as the modes of the optical cavity. Photons with energies that are just a little bit higher than the band-gap energy will have the highest gain, and the modes that are closest to the apex of the gain curve will have the most power. The widening of the gain curve may also result in an increase in the number of "side modes" created, depending on the operating conditions. Fabry-Perot (FP) lasers are single spatial mode lasers that can accommodate a large number of longitudinal modes in a single wavelength range. It will be possible to use an FP laser at a variety of cavity modes because of the high gain bandwidth of the lasing medium. The number of lasing modes available in an FP laser can fluctuate as a result of differences in current or temperature.

Diode lasers that operate on a single longitudinal mode can be developed. These high-stability, single-frequency diode lasers are used in spectroscopy and metrology, as well as frequency standards. Distributed feedback (DFB) and distributed Bragg reflector (DBR) lasers are two types of single-frequency diode lasers.

Formation of laser beam

After leaving the chip, the beam rapidly diverges (expands) due to diffraction, often at 30 degrees vertically by 10 degrees laterally. A collimated beam like that produced by a laser pointer can only be achieved with the use of a lens. Cylindrical lenses and other optics are used to create a circular beam when necessary. Because the vertical and lateral divergences differ for single spatial mode lasers using symmetrical lenses, the collimated beam takes on an oval shape. Using a red laser pointer, this may be seen clearly.

There are many different types of laser diodes that have been developed since the simple diode mentioned above was first introduced a few decades ago.

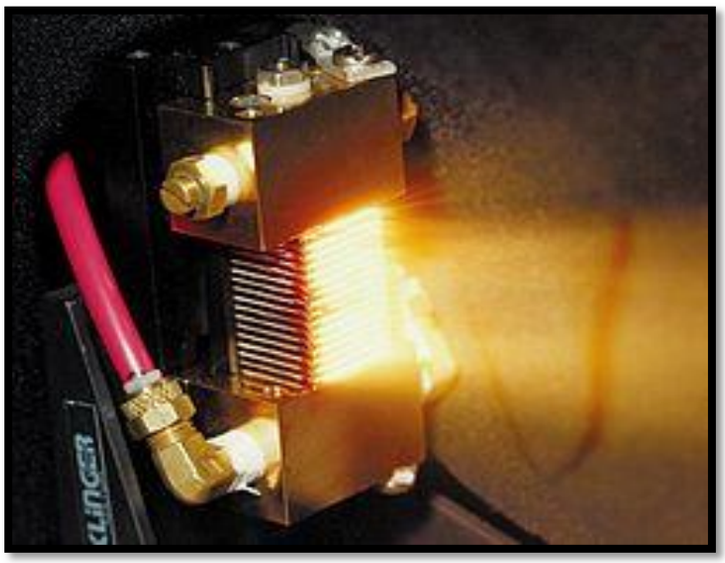
Applications

Telecommunications, scanning and spectrometry

Telecommunication use laser diodes extensively as modulated and readily connected fiber optics light sources. It is common to find them in rangefinders and other gadgets that measure distances. Barcode scanners are another typical application. Laser pointers commonly use visible red or green lasers (green lasers were introduced later). In the printing industry, both low- and high-power diodes are widely utilized as light sources for scanning (input) of images and for the production of printing plates (output) at extremely high speeds and resolutions. Laser diodes in CD players, CD-ROMs, and DVD technology emit infrared and red light. Violet lasers are used in both HD DVD and Blu-ray technology to improve picture quality. Laser absorption spectrometry (LAS) is a technique that uses diode lasers to analyze or monitor gas-phase concentrations of various species at fast speeds and at cheap cost. Solid-state lasers powered by high-power laser diodes, for example, are used in industrial applications such as heat treatment, cladding, and seam welding.

Laser diodes have a wide variety of applications. They are vital for applications in the mass market because of the cheap cost of mass-produced diode lasers, which are available at low cost. but larger solid-state lasers or optical parametric oscillators could serve most needs. Since light has so many various features (power, wavelength, spectral and beam quality, polarization, etc.), it's helpful to categorize applications using these fundamental properties when thinking about diode lasers.

The "directed energy" quality of an optical beam is a primary consideration in many diode laser uses. Laser printers, barcode scanners, image scanners, illuminators, designators, optical data recording, combustion ignition, laser surgery, industrial sorting, industrial machining, and directed energy weapons are all examples of this type of technology. There is a mix of existing and new uses for these applications.



Uses in medicine

In the medical and dental fields, diode lasers have found a slew of innovative uses. For modest soft tissue treatments, the devices' smaller size and lower cost[16] and improving user friendliness make them an attractive option for doctors. There are a wide variety of diode wavelengths, from 810 to 1,100 nm, and they are not employed for cutting or ablation. The laser's beam does not cut through soft tissue; instead, a hot, burned glass tip does the cutting. The distal end of the laser's tip absorbs most of the laser's irradiation and warms it to temperatures between 500° and 900°C. It is possible to cauterize and carbonize soft tissue using the tip's extreme heat, making it an effective tool for cutting delicate tissue. When used on soft tissue, diode lasers can cause significant collateral thermal damage.

Laser diodes can be used in some applications because of their inherent coherence. Holography, interferometric distance measuring, coherent communications and chemical reaction control are all examples.

Range-finding, communications, infrared countermeasures, spectroscopic sensing and generation of radio-frequency or terahertz waves, preparation of atomic clock states and quantum key cryptography, frequency doubling and conversion and water purification (in the UV) are all examples of applications where laser diodes are used for their "narrow spectral" properties (where a particular wavelength of light would cause a substance such as a porphyrin to become chemically active as an anti-cancer agent only where the tissue is illuminated by light).

A technique is known as "mode-locking" allows laser diodes to produce extremely brief pulses of light. It can be used for clock distribution in high-performance integrated circuits, high-power spectroscopic sensors, arbitrary waveform generation for radio-frequency waves, photonic sampling for analogue-to-digital conversion, and code-division multiple-access systems for secure communications.

Common wavelengths and uses

Visible light

405 nm – InGaN blue-violet laser, in Blu-ray Disc and HD DVD drives

445–465 nm – InGaN blue laser multimode diode recently introduced (2010) for use in mercury-free high-brightness data projectors

510–525 nm – InGaN Green diodes recently (2010) developed by Nichia and OSRAM for laser projectors.

635 nm – AlGaInP better red laser pointers, same power subjectively twice as bright as 650 nm

650–660 nm – GaInP/AlGaInP CD and DVD drives, cheap red laser pointers

670 nm – AlGaInP bar code readers, first diode laser pointers (now obsolete, replaced by brighter 650 nm and 671 nm DPSS)

Infrared[edit]

760 nm – AlGaInP gas sensing: O_2

785 nm – GaAlAs Compact Disc drives

808 nm – GaAlAs pumps in DPSS Nd:YAG lasers (e.g., in green laser pointers or as arrays in higher-powered lasers)

848 nm – laser mice

980 nm – InGaAs pump for optical amplifiers, for Yb:YAG DPSS lasers

1,064 nm – AlGaAs fiber-optic communication, DPSS laser pump frequency

1,310 nm – InGaAsP, InGaAsN fiber-optic communication

1,480 nm – InGaAsP pump for optical amplifiers

1,512 nm – InGaAsP gas sensing: NH_3

1,550 nm – InGaAsP, InGaAsNSb fiber-optic communication

1,625 nm – InGaAsP fiber-optic communication, service channel

1,654 nm – InGaAsP gas sensing: CH_4

1,877 nm – GaInAsSb gas sensing: H_2O

2,004 nm – GaInAsSb gas sensing: CO_2

2,330 nm – GaInAsSb gas sensing: CO

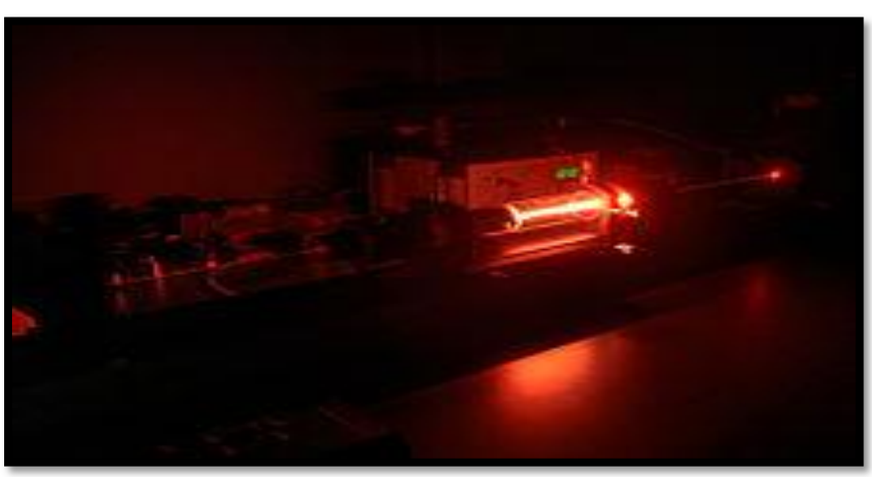
2,680 nm – GaInAsSb gas sensing: CO_2

3,030 nm – GaInAsSb gas sensing: C_2H_2

3,330 nm – GaInAsSb gas sensing: CH_4

He-Ne laser

This type of laser is known as a "He-Ne" laser because the gain medium is a 10-1 mixture of helium and neon at a total pressure of around 1 torr inside of a small electrical discharge. An extremely popular and commonly used laser, the He-Ne, emits light at 632.8 nm - a wavelength that falls inside the visible red spectrum.



History of development of He-Ne laser

These 1150-nm infrared lasers were the first gas lasers, as well as continuous-wave output devices. It was necessary to investigate additional neon transitions in order to determine whether or not they could also be employed to generate a population inversion for the purpose of making the laser visible. Lasers with 633 nm

wavelengths are the most commonly used in the visible spectrum because they have the highest gain. If you're looking to produce a red, orange, yellow, or green laser, you can use mirror coatings with the highest reflectance at these other wavelengths to achieve this goal. As far as 100 nm in the far-infrared, the visible to 540 nm range of stimulated emissions has been well-documented.

Because visible transitions have a lower gain, these lasers are typically more expensive and less efficient. However, due to the lossy nature of the cavities and mirrors at that wavelength, the 3.39 m transition cannot be used in a standard He-Ne laser (with a different intended wavelength). A problem with superluminescence at 3.39 m is that it can deplete the stimulated emission medium of power, necessitating further suppression in high-power He-Ne lasers with particularly long cavities.

He-Ne lasers operate at a wavelength of 632.8 nm, which is located in the red portion of the visible spectrum. The first continuous infrared He-Ne gas laser was demonstrated at Bell Telephone Laboratories in December 1960, just 18 months earlier.

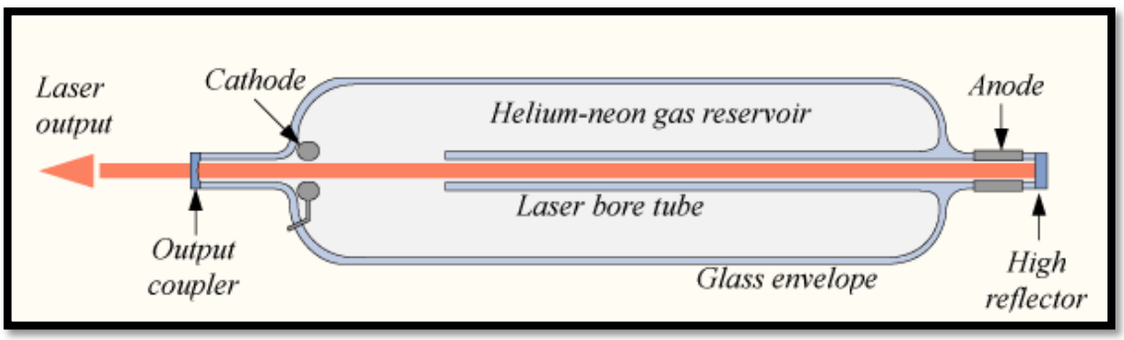
Construction of He-Ne

A low-pressure glass envelope houses the laser's gain medium, which is actually a mixture of helium and neon gases in a 10:1 ratio. In order to excite helium atoms, the gas mixture has a high concentration of gas Some of the excitation-stimulated neon atoms collide with excited helium atoms, resulting in a radiance of 632.8 nm from some of the neon atoms. The non-laser lines would be caused by the neon atoms being excited to lower excited states if helium were absent.

Commercial He-Ne lasers are small compared to other gas lasers. They usually have cavity lengths of 15 to 50 cm, but can go up to about 1 meter to get the highest power. They have optical output power levels of 0.5 to 50 mW.

The actual vacuum wavelength of the red He-Ne laser at 633 nm, or about 632.816 nm in air, is 632.991 nm. This is the wavelength in which it operates. Modes that are stimulated emit at frequencies within 0.001 nm of this value, which shifts due to thermal expansion and contraction of the cavity, are found. Due to a technique called power comparison between two longitudinal modes with opposing polarizations, frequency-stabilized variants allow for an accurate specification of one mode's wavelength down to 1 part in 108 of a wavelength. An iodine absorption cell can be

used to stabilize the laser's frequency (or wavelength) to a precision of 2.5 parts in 1011.



He-Ne laser plasmas generate population inversion and amplification of light when helium atoms smash with intense electrons in the gas mixture. In the 23S1 and 21S0 (LS or Russell–Saunders coupling, the front number 2 implies that an excited electron has n = 2 states) excited states of helium atoms, there are two types of metastable states. The 5s2 and 4s2 (Paschen notation) levels of neon are nearly coincident with the energy levels of the two metastable He states, resulting in a selective and efficient conversion from helium to neon in collisions between these atoms. This is how the reaction equations depict the movement of excitation energy.

$$He^*(2^3S_1) + Ne^1S_0 \rightarrow He(^1S_0) + Ne^*4s_2 + \Delta E,$$

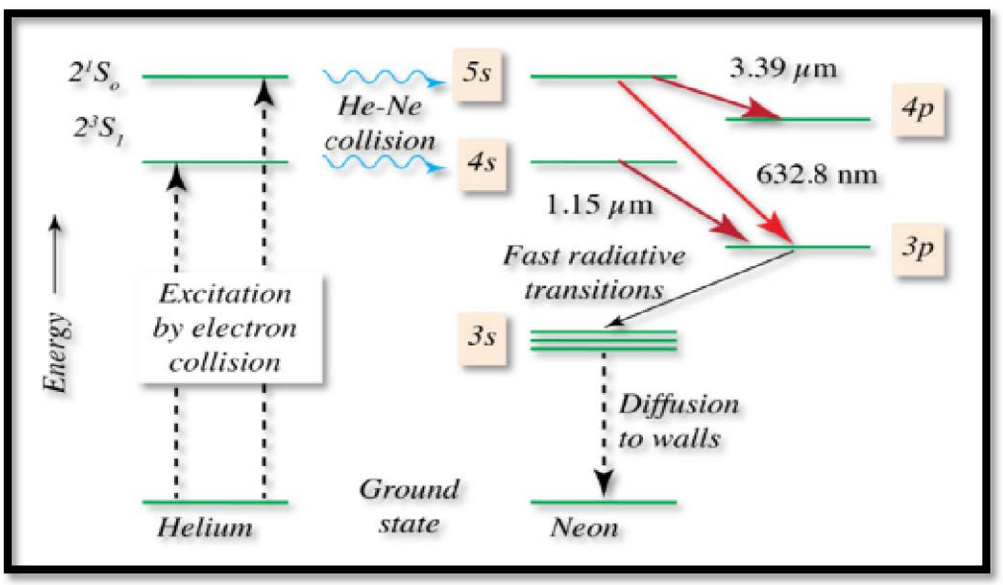
$$He^*(2^1S) + Ne^1S_0 + \Delta E \rightarrow He(^1S_0) + Ne^*5s_2,$$

Where * represents an excited state, and ΔE is the small energy difference between the energy states of the two atoms, of the order of 0.05 eV, or 387 cm^{-1}, which is supplied by kinetic energy. As the levels of neon 4s2 and 5s2 are excited and transferred, their population grows many times over. Population inversion occurs when the population of these two upper levels exceeds the population of the lower level 3p4, with which they are optically associated. A narrow band at 1.15 m (corresponding to the 4s2 to 3p4 transition) and a thin band at 632.8 nm are capable of being amplified by the medium (corresponding to the 5s2 to 3p4 transition).

In the 3s state, the 3p4 level is fast emptied by radiative decay to the ground state.

The final step in using optical amplification to create an optical oscillator is to place highly reflecting mirrors at either end of the amplifying medium so that a wave in a

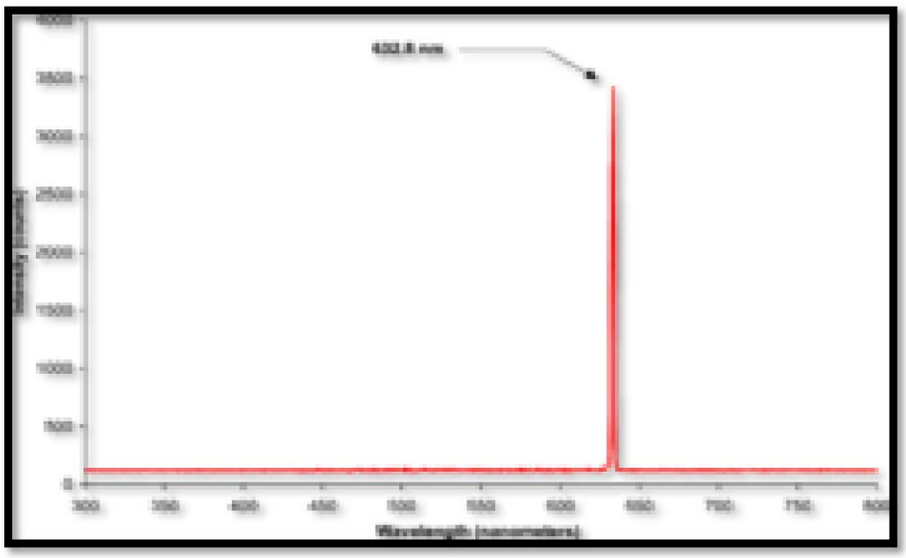
specific spatial mode will reflect back upon itself and gain more power in each pass than is lost due to transmission through the mirrors and diffraction. At this point, radiation from the longitudinal modes will rapidly build up until gain saturation is reached, resulting in a stable and continuous laser beam output through the front mirror (which is normally 99 % reflecting).



Energy levels in a He-Ne laser

Doppler broadening is a dominant factor in the gain bandwidth of the He-Ne laser because of the low gas pressure, and the whole bandwidth of the 633 nm transition is only about 1.5 GHz. There can be anywhere from two to eight longitudinal modes oscillating at the same time in a cavity with a typical length of 15 to 50 cm (however, single-longitudinal-mode units are available for special applications). Due to the red He-Ne laser's high spatial quality, extended coherence length, and visible output, this laser is an ideal holographic source and spectroscopy wavelength reference. One of the benchmark systems for defining the meter is a stable He-Ne laser.

He-Ne red lasers were frequently utilized in barcode scanners at supermarket checkout counters prior to the invention of inexpensive, abundant diode lasers. He-Ne lasers operating at 633 nm in a ring laser arrangement have been used in laser gyroscopes. Research and educational optical laboratories frequently use He-Ne lasers.



Applications

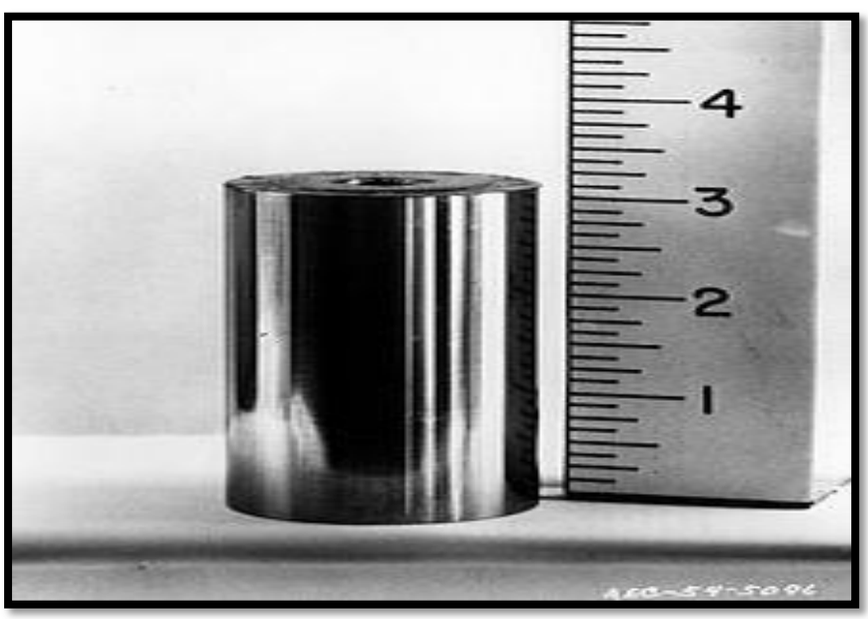
He-Ne lasers in red can be used for a wide range of industrial and scientific applications. Their low cost and ease of operation compared to other visible lasers that can produce the same quality spatial coherence (a single-mode Gaussian beam) and extended coherence length make them popular in laboratory demonstrations in the field of optics (however, since about 1990 semiconductor lasers have offered a lower-cost alternative for many such applications). Pioneer Laser Disc players have been using HeNe tube lasers since 1978, when Toshiba and NEC began manufacturing them for the company. Infrared laser diodes were used instead in the 1984 model lineup. After the format's demise in 2009, In all of its subsequent players, Pioneer continues to use laser diodes.

1-2 Radiosources

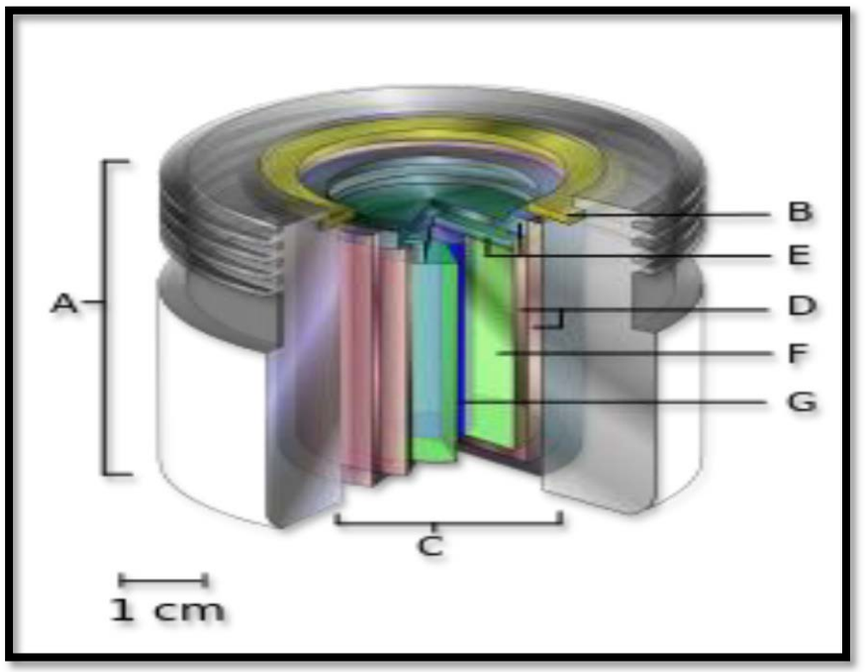
Radioactive sources are defined as a known quantity of a radionuclide that emits ionizing radiation; gamma rays, alpha particles, beta particles, and neutron radiation are the most frequent types of radiation. One of the most common uses of radioactive sources is in the treatment of target materials, where the radiation acts as an ionizing agent. The other is in the calibration of radiometric processes and radiation-protection equipment. In the paper and steel industries, for example, they are used for thickness gauging. If the source is in a container (very penetrating radiation), it can be sealed or it can be deposited on the surface (weakly penetrating). Radiation therapy, industrial

radiography, food irradiation, sterilization, vermin disinfestation, and irradiation crosslinking of polyvinyl chloride (PVC) are some of the uses for irradiation sources in medicine. The selection of radionuclides is based on the type and nature of radiation they emit, the strength of their emission, and the half-life of the decay process. Cobalt-60, iridium-192 and strontium-90 are some of the radionuclides that are most frequently utilized. The Becquerel is the SI unit of source activity, but the historical unit Curies is still in use in some countries, such as the United States, despite the fact that the NIST highly recommends the SI unit. The usage of the SI unit is required by the European Union in order to ensure patient safety.

Typically, an irradiation source's activity diminishes below useful levels after 5 to 15 years before it ceases to be helpful. Calibration sources based on long-lived radionuclides, on the other hand, can be employed for a considerably longer period.



A final view of a new sealed cesium-137 radiation source



The radioactive source used for external beam radiation therapy (shown in cutaway form) The file page has a lettering key.

This means that the source is either encased inside a capsule or is securely attached to the surface where it lives. stainless steel, titanium, platinum or another inert metal are commonly used to make capsules. When radioactive material is stored in sealed containers, it is virtually impossible for it to leak out due to user error, but because the containers are not designed to reduce radiation, additional shielding is required for safety. As long as the source isn't chemically or physically mixed in with the medium, sealed sources are virtually universally employed.

Categorisation of sealed sources A radioactive hazard symbol developed by the International Atomic Energy Agency in 2007 for IAEA Category 1, 2, and 3 sources, which are defined as dangerous sources that can cause death or serious injury.

When classified as a minimally hazardous source by the International Atomic Energy Agency (IAEA), sealed sources are at the bottom of the list (Humans can be seriously injured by a harmful source). Source activity (A) and activity with a low potential for harm (D) are divided by A and D, respectively, to arrive at the A/D ratio.

This classification does not include detectors such as smoke detectors, which have a very low radioactive output.

For radiometric instrument calibration, calibration sources are typically used. This includes in-process monitoring and radiological protection applications, among other things. Capsule sources, in which the radiation is effectively emitted from a single point, are utilized for the calibration of beta, gamma, and X-ray instruments. High-level sources are typically employed in a calibration cell, which consists of a room with thick walls to protect the operator as well as the ability to operate the source exposure from a distance. The plate source is a type of calibration source that is commonly used for radioactive contamination instruments. Large-area radiation detectors used in contamination surveys and people monitoring are calibrated using a known amount of radioactive material mounted to its surface, such as an alpha and/or beta emitter. These types of measurements are frequently made using counts per unit time received by the detector, such as counts per minute or counts per second.

The plating source emitting material must be on the surface to avoid attenuation by a container or self-shielding due to the material itself. For alpha particles, a tiny mass is all that is needed to stop them, this is critical. In open-air, the Bragg curve demonstrates the attenuation effect.

Unsealed sources

Unsealed sources are sources that are not confined in a container that is permanently sealed, and they are commonly used in the medical industry. The source must be dissolved in a liquid in order for it to be delivered to or ingested by a patient. As with radioactive tracers, unsealed sources are also used in the industry for leak detection in

a similar manner as leak detection with sealed sources. Unsealed sources are used in a similar manner as leak detection with sealed sources.

Disposal

Disposal of radioactive sources that have reached the end of their useful lives is fraught with difficulties that are similar to those encountered in the disposal of other types of nuclear waste, but to a lesser degree. It is possible that when a low-level source has been decommissioned, it will become inactive enough to be disposed of via standard waste disposal methods, which are typically landfill. This is called decommissioning. Aside from that, other methods of disposal are comparable to those used for higher-level radioactive waste, with boreholes being excavated to varied depths depending on how active the waste is being disposed of. The Goiânia disaster, which resulted in the deaths of a large number of individuals, is one of the most well-known examples of a failure to properly dispose of a high-level source of radioactivity.

Cesium CS

Caesium-137 (13755Cs), also known as radiocaesium, is a radioactive isotope of caesium that is produced as a byproduct of the nuclear fission of uranium-235 and other fissionable isotopes in nuclear reactors and nuclear weapons. Caesium-137 ($^{137}_{55}Cs$) is a radioactive isotope of caesium that is produced as a byproduct of nuclear fi Natural fission of uranium-238 also produces trace amounts of uranium-238 in trace amounts. It is one of the most problematic fission products with a short to medium lifetime, and it is also one of the most dangerous.

^{137}Cs is easily volatilized in the environment and transported through the atmosphere over exceptionally long distances, as was the case in the Chernobyl nuclear accident and atomic bomb blasts, due to the element's low boiling point (671 degrees Celsius, or 1240 degrees Fahrenheit). When radioactive fallout is deposited on soil, it is easily transported and spread throughout the environment as a result of the high water solubility of caesium's most common chemical components, which are salts, which are present in large concentrations. The discovery of ^{137}Cs was made by Glenn T. Seaborg and Margaret Melhase in 1959.

A sealed caesium-137 radioactive source	
General	
Symbol	^{137}Cs
Names	caesium-137, Cs-137
Protons	55
Neutrons	82
Nuclide data	
Natural abundance	0 (trace)
Half-life	30.17 y ± 0.03 y[1]
Parent isotopes	^{137}Xe (β^-)

Decay products	^{137m}Ba ^{137}Ba
Isotope mass	136.907 u
Spin	$^{7}/_{2}$+
Decay modes	
Decay mode	Decay energy (MeV)
β- (beta decay)	0.5120[2]
γ (gamma-rays)	0.6617
Isotopes of caesium Complete table of nuclides	

Decay

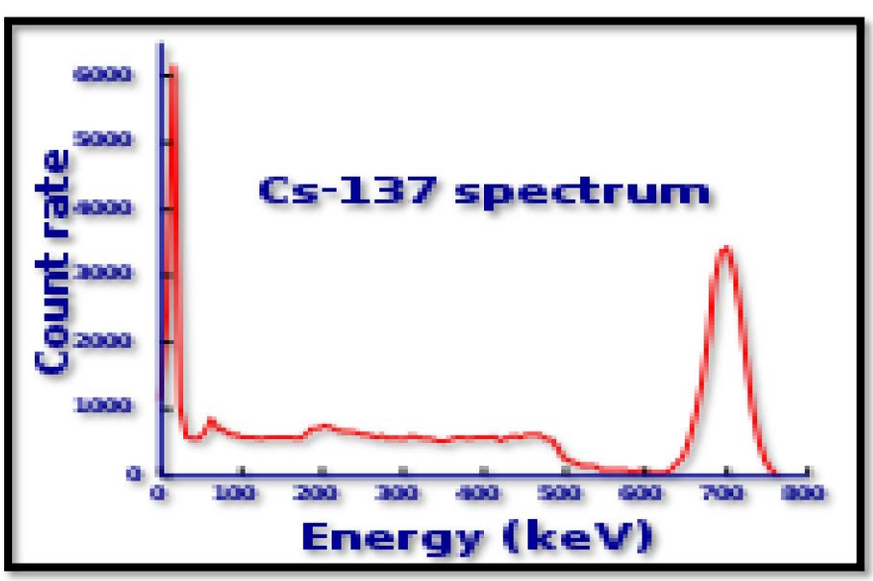
The half-life of caesium-137 is approximately 30.17 years. [1] The beta emission decay of approximately 94.6 percent of the barium nucleus resulted in the formation of barium-137m, a metastable nuclear isomer of barium (137mBa, Ba-137m). The remainder is used to directly populate the stable ground state of barium-137. All of caesium-137's gamma-ray emissions are produced by metastable barium, which has a half-life of around 153 seconds and releases photons with an energy of 0.6617 MeV. [3] In 85.1 percent of all occurrences, ^{137}Cs decays result in the production of gamma rays. Caesium-137 has a specific activity of 3.215 terabecquerels per gram of the element (TBq).

Uses

Caesium-137 has a wide range of applications. It is used to calibrate radiation-detection systems in modest doses, and it is quite effective. Radiation treatment is one of the applications in medicine. In industry, it is used in flow meters, thickness gauges, moisture-density gauges (for density measurements, with americium-241/beryllium providing the moisture reading) and gamma-ray well logging systems, among other applications.

Caesium-137 is not frequently used in industrial radiography because it is difficult to produce a high specific activity material with a well-defined (and small) structure. This is because Caesium derived from spent nuclear fuel contains both stable Caesium and long-lived Cs-135, making it difficult to generate a high specific activity material with a well-defined (and small) structure. Additionally, the higher specific activity caesium sources are more likely to be made from caesium chloride (CsCl), which means that if a radiography source is destroyed, the contamination would spread more quickly. It is feasible to create water-insoluble caesium sources (using various ferrocyanide compounds such as $Ni_2Fe(CN)_6$, ammonium ferric hexacyano ferrate (AFCF), Giese salt, ferric ammonium ferrocyanide) but their specific activity will be significantly reduced. In radiography, a large emission volume will degrade the image quality. Iridium-192 and cobalt-60, $^{60}_{27}Co$, are the metals of choice for radiography because they are chemically inert and may be produced with significantly greater specific activity by activating stable cobalt or iridium in high flux reactors.

Since 1945, caesium-137, a man-made isotope, has been used to date wine and identify forgeries and to determine the age of sedimentation. Caesium-137 is also used as a radioactive tracer in geologic research to measure soil erosion and deposition.



Health risk of radioactive caesium

In the presence of water, the element caesium-137 interacts to form a water-soluble compound (caesium hydroxide). Biologically speaking, caesium behaves in a similar way to potassium and rubidium. In the body, once entering it, caesium is disseminated throughout the body in a more or less homogeneous manner, with the highest amounts occurring in soft tissue.114 Caesium has a half-life of approximately 70 days in the biological environment.

The results of a 1961 experiment showed that mice given a dose of 21.5μ Ci/g died within 30 days, implying a lethal dose of 245 μg/kg. Using a similar experiment, researchers discovered that when dogs are exposed to an entire body burden of 3800 μci/kg (140 MBq/kg, or roughly 44 g/kg) of caesium-137 (and 950 to 1400 radiation), they die within 33 days, but animals exposed to half of that burden survive for up to a year. Experiments of significance have revealed a remarkably high concentration of ^{137}Cs in pancreatic exocrine cells, which are the cells that are most susceptible to tumor growth. When Bandazhevsky performed autopsies on six children who died in the polluted area near Chernobyl, where they also discovered a higher incidence of pancreatic tumors, he discovered that their pancreatic tissue had a concentration of 137Cs 40-45 times higher than their liver, demonstrating that pancreatic tissue is a strong accumulator and secretor of radioactive cesium into the intestine. Accidental ingestion of caesium-137 can be treated with Prussian blue (FeIII 4[FeII $(CN)_3$), which binds to it chemically and reduces the biological half-life to 30 days.

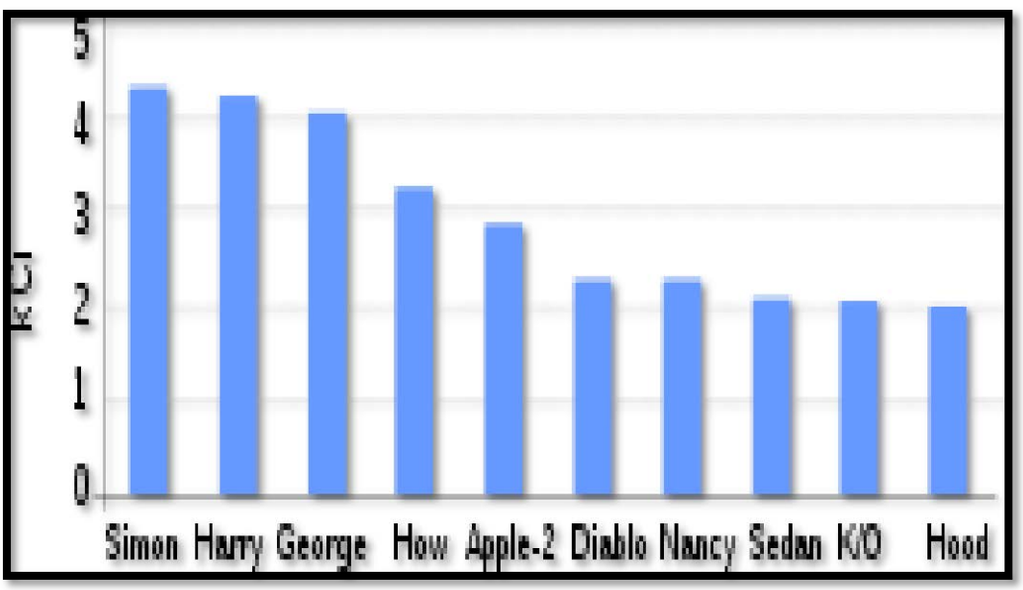
Radioactive caesium in the environment

Nuclear weapons testing and certain accidents, on the other hand, resulted in the release of radioactive isotopes such as cesium-137 into the environment in virtually every case. These include the Chernobyl disaster, as well as the Fukushima Daiichi disaster and other recent nuclear disasters, such as the Three Mile Island disaster.

Chernobyl disaster

To this day and for the foreseeable future, the most dangerous radionuclides for human health in the exclusion zone around Chernobyl are caesium-137 and strontium-90, which have a half-life of around 30 years and a high biological uptake

rate. In Germany, caesium-137 pollution ranged from 2000 to 4000 Bq/m2 following the Chernobyl incident. citations are required A total of 500 kilos of caesium-137 has been deposited across Germany, corresponding to a contamination rate of 1 mg/km2. For the first time in 26 years, several reindeer and sheep exceeded the permitted limit of 3000 Bq/kg in Scandinavia. Caesium-137 from Chernobyl has degraded by 50% as of 2016, but it could have been locally concentrated by factors considerably bigger than that as of 2016.

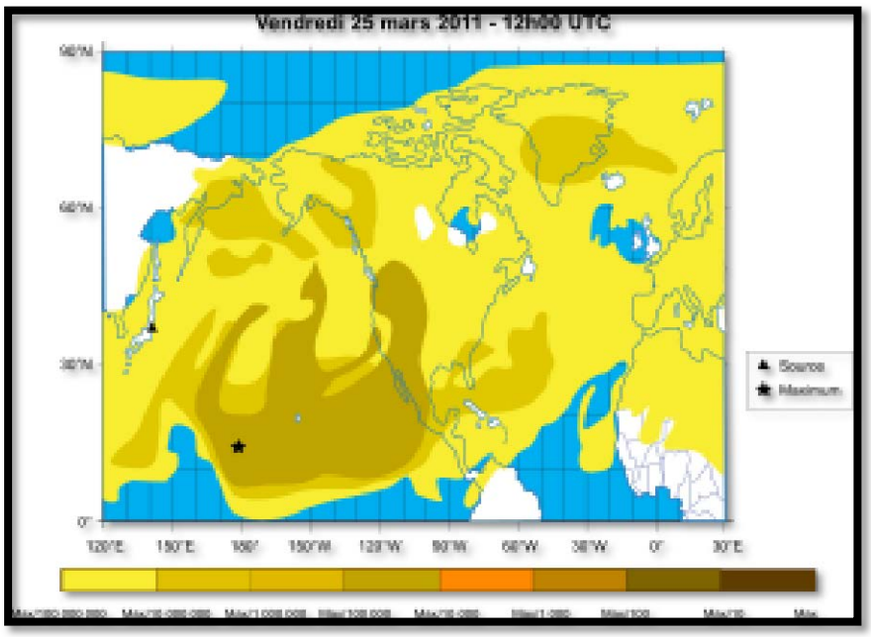


Caesium-137 deposits at the Nevada Test Site, ranked from highest to lowest, are shown in the table below. There were two test explosions from Operation Upshot–Knothole in 1953, and two test explosions from Operation Tumbler–Snapper in 1952, named “Simon” and “Harry,” respectively.

Medium-lived fission products				
Prop:	$t_{½}$	Yield	Q *	βγ *
Unit:	(a)	(%)	(keV)	
^{155}Eu	4.76	0.0803	252	βγ
^{85}Kr	10.76	0.2180	687	βγ
^{113m}Cd	14.1	0.0008	316	β
^{90}Sr	28.9	4.505	2826	β
^{137}Cs	30.23	6.337	1176	βγ
^{121m}Sn	43.9	0.00005	390	βγ
^{151}Sm	88.8	0.5314	77	β

Caesium-137 has been identified as the primary source of risk for human health in Fukushima. Soil and other materials polluted with caesium can be stripped of 80 to 95 percent of the caesium using a variety of procedures, all of which are being studied. Hydrothermal blasting is one of these methods. Special burial locations would only be required for the caesium-ferric ferrocyanide precipitate (Prussian blue). An annual exposure level of 1 mSv over the background level is the goal. While the most polluted area, where radiation levels are greater than 50 mSv/year, must remain off-limits, decontamination of some parts that are currently less than 5 mSv/year may be allowed to allow 22,000 residents to return. The citation for this statement is not available.

Caesium-137 contamination in the environment is largely a result of human activity (human-made). The nuclear fission of plutonium and uranium yields caesium-137, which then decays into barium-137. About 1.7 billion years had passed before the Chicago Pile-1, the world's first man-made nuclear reactor, was constructed in late 1942. One can tell if the sealed container's contents were created before or after the first atomic bomb explosion (Trinity test, 16 July 1945), which released gamma rays and immediately dispersed trace amounts of this isotope over the world. To verify the authenticity of rare wines, such as the "Jefferson bottles," academics have utilized this method. The activity of 137Cs can also be used to date soils and sediments on the surface.



Fukushima nuclear disaster air caesium-137 concentration, 25 March 2011.

Coblit

Cobalt-60 (^{60}Co) is a radioactive isotope of cobalt that was created artificially and has a half-life of 5.2713 years. In nuclear reactors, it is created artificially and used in various applications. It is necessary to neutron activate bulk samples of the monoisotopic and mononuclidic cobalt isotope ^{59} Co in order to conduct deliberate industrial production .[4] While nuclear power plants produce measurable quantities as a byproduct of normal operation, these numbers can also be observed externally when leaks occur. In the absence of additional cobalt, the ^{60}Co created in the reactor's steel structures is mostly the consequence of numerous stages of neutron activation of iron isotopes in the reactor's steel structures. Simplest is 58Fe activation. Nickel-60 is the stable isotope of ^{60}Co after ^{60}Co undergoes beta decay (^{60}Ni). Activation and decay of the nickel nucleus produce two 1.17 and 1.33 MeV gamma ray emissions. This leads to the following general nuclear reaction (activation and decay) equation:

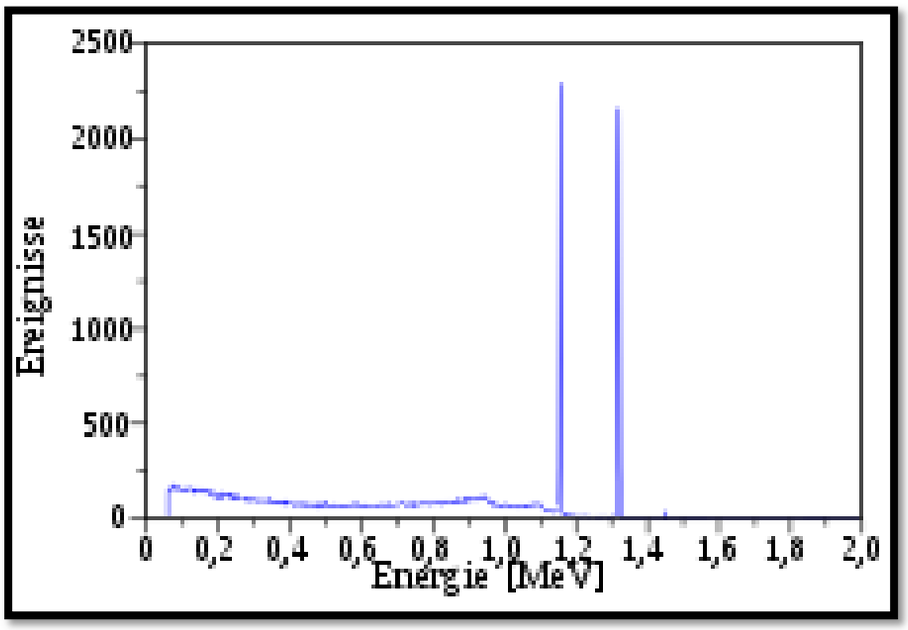
$$^{59}_{27}Co + \text{n} \rightarrow {}^{60}_{27}Co \rightarrow {}^{60}_{28}Ni + \text{e}^- + \nu\text{e} + \gamma \text{ rays.}$$

General	
Symbol	^{60}Co
Names	cobalt-60, Co-60
Protons	27
Neutrons	33
Nuclide data	
Natural abundance	trace
Half-life	5.27 years[1]
Isotope mass	59.9338222 u
Spin	5+

Decay modes	
Decay mode	Decay energy (MeV)
β (beta decay)	0.317[2]
γ (gamma-rays)	1.1732,1.3325
Isotopes of cobalt Complete table of nuclides	

Activity

One gram of ^{60}Co has a radioactive activity of 44 TBq, which corresponds to its half-life (about 1100 curies). The absorbed dose constant is a function of the decay energy and the time it takes for the dosage to reach equilibrium. At a distance of one meter from the source, ^{60}Co emits 0.35 mSv/(GBq h). Based on distance and activity, it is possible to calculate the corresponding dose. It takes an hour for the radiation dose to reach one millisievert (mSv) at one-meter distance from a ^{60}Co source with an activity equal to 60 millisieverts (mSv). In just a few seconds, the same amount can be delivered via oral ingestion of ^{60}Co. For classroom experiments, a test source with an activity of 100kBq is employed. There are nondestructive material testing devices that utilize sources with activity levels of more than one trillionth. Because of the large -energies, there is a mass difference of 0.003 u between ^{60}Ni and ^{60}Co. About 30 times more powerful than ^{238}Pu, this has a watts-per-gram output of nearly 20



Decay

Decomposition patterns of 60 and ^{60m} Co are shown in the diagram. The most common -decay transitions are depicted. Population of the energy level 2.1 MeV, with a maximum of 665.26 keV, by -decay has a chance of 0.0022 percent. Six distinct gamma-ray frequencies are generated by the energy transfers between the three layers of the pyramid. Those are clearly indicated in the illustration. Internal conversion energies are a long way from the primary energy levels. It has a half-life of 10.467 minutes. It can go through an internal transition to ^{60} Co and generate 58.6 keV gamma rays, or it can go through a β-decay into ^{60} Ni with a low chance of 0.22 %.

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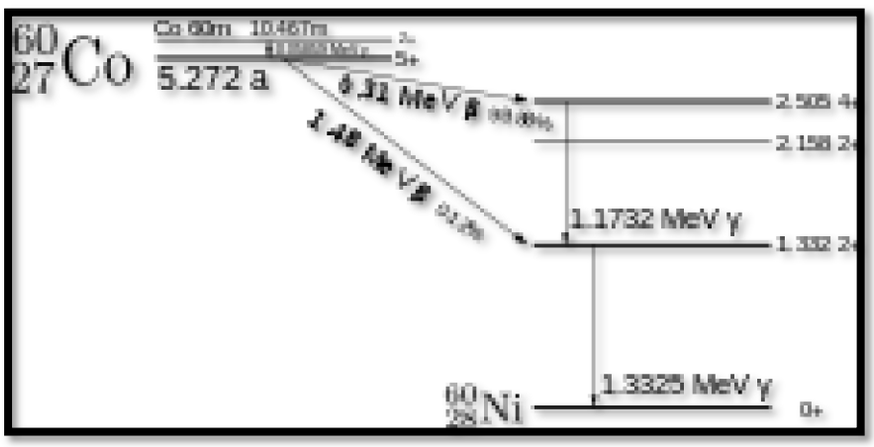


Applications

There are a number of advantages to using ^{60}Co in conjunction with other high-intensity gamma-ray emitters that have a reasonably long half-life (5.27) when compared to other gamma-ray sources of comparable intensity. Because of their low energy and ease of shielding, gamma-ray emission lines have energies in the region of 1.3 MeV and are quite penetrating despite the fact that the gamma-ray decay energy is moderate and readily shielded. When compared to other gamma sources, such as caesium-137, the physical properties of cobalt, such as its resistance to bulk oxidation and low solubility in water, provide some advantages in terms of safety in the event of a containment breach, according to the National Institute of Standards and Technology (NIST). ^{60}Co is used mostly in the following industries:

As a tracer for cobalt in chemical reactions

Sterilization of medical equipment.

Radiation source for using beams of gamma medical radiotherapy.[9] Cobalt therapy, using beams of gamma rays from ^{60}Co

Teletherapy machines to treat cancer.

Radiation source for industrial radiography.

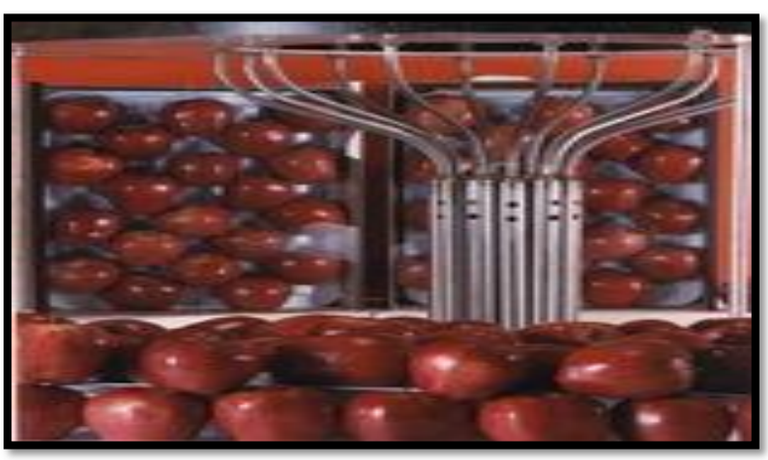
Radiation source for leveling devices and thickness gauges.

Radiation source for pest insect sterilization.

As a radiation source for food irradiation and blood irradiation.

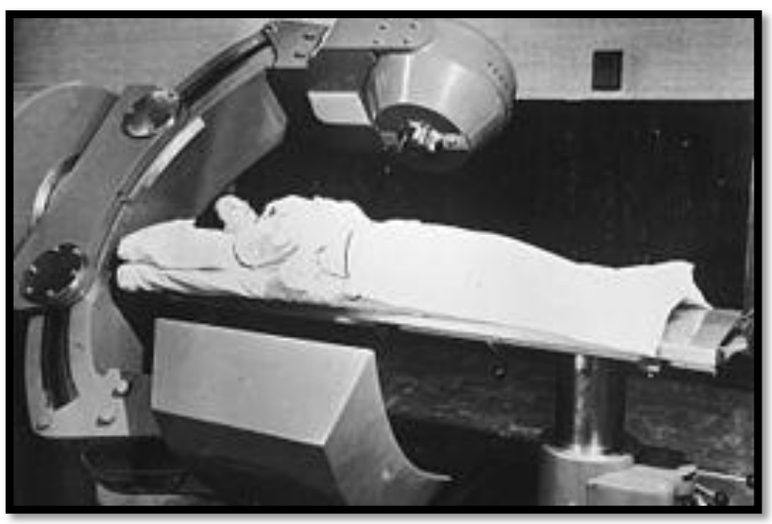
Cobalt has been discussed as a "salting" element to add to nuclear weapons, to produce a cobalt bomb, an extremely "dirty" weapon which would contaminate large areas with ^{60}Co, nuclear fallout, rendering them uninhabitable. In one hypothetical design, the tamper of the weapon would be made of ^{59}Co. When the bomb exploded, the excess neutrons from the nuclear fission would irradiate the cobalt and transmute it into ^{60}Co. No nation is known to have done any serious development of this type of weapon.

60 Co gamma-ray scanner used for car security screening at Super Bowl XLI (2007)



Prototype irradiator for food irradiation to prevent spoilage, 1984. The 60Co is in the central pipes

60Co needle fixed in tumors for radiotherapy, around 1955.



60Co teletherapy machine for cancer radiotherapy, early 1950s.

Brookhaven plant mutation experiment using ^{60}Co source in the pipe, center.

60Co source for sterilizing screwflies in the 1959 Screwworm Eradication Program

Occurrence

Because there is no naturally occurring ^{60} Co on Earth, a slow neutron source is used to bombard a ^{59}Co target in order to produce synthetic ^{60}Co. The neutron flux in a nuclear reactor can also be utilized for this purpose, as can Californium-252, moderated through water. Control rods made of cobalt can be substituted in the CANDU reactors to activate 59Co. Hope Creek Nuclear Generating Station in the United States is now producing it in a BWR. There are a few fuel assemblies in place of which the cobalt targets are used instead.

$^{59}Co + n \rightarrow {}^{60}Co$

Safety

Some of the ^{60}Co is expelled in faeces after entering a living creature (such as a human). Gamma radiation can cause cancer in tissues such as the liver, kidneys, and bones if it is inhaled for an extended period of time. The absorbed cobalt is excreted in the urine over time.

Steel contamination

There are several uses for cobalt, including the production of steel. The radioactivity observed in a variety of iron-based products can be attributed to the improper disposal of 60Co in scrap metal.

The construction of 1700 apartments in Taiwan made of steel polluted with cobalt-60 was completed around 1983. Between 9 and 20 years, around 10,000 individuals lived in these buildings. Unwittingly, they received a radiation amount of 0.4 Sv. There was a lower cancer death rate in this large group than in the general Taiwan population, contrary to the linear no-threshold model's prediction. If the radiation hormesis idea is correct, these findings support it.

According to the US Customs and Border Patrol, Petco recalled several models of steel pet bowls because they were producing low quantities of radioactivity in August 2012. The steel had been polluted with 60Co, which was the cause of the radiation.

ASOS belts were seized and kept in a US radioactive storage facility in May 2013 after testing positive for ^{60} Co. The belts were offered by the online retailer ASOS.

Incidents involving medical radiation sources

In the Samut Prakan radiation disaster of 2000, an obsolete radiotherapy head carrying a ^{60}Co source was unintentionally sold to trash collectors in Bangkok, Thailand. After an unprotected junkyard employee disassembled the head and removed its source, the source was left exposed for days. Ten persons, including scrap collectors and junkyard employees, were exposed to high quantities of radiation and fell sick. Three junkyard employees died as a result of their radiation exposure, which was estimated to be more than 6 Gy. Afterwards, the source was retrieved by Thai police in a secure manner.

At a gas station in Mexico City, a truck transporting an abandoned 111 TBq ^{60}Co teletherapy source from a hospital in Tijuana to a radioactive waste storage site was kidnapped. It was the first time this had happened. It was discovered that the source had been removed from its shielding before the vehicle could be retrieved, which was fortunate. It was discovered in an adjacent field, completely undamaged. Contrary to the sensationalist headlines, the radiation disease was mild enough that the suspects were quickly released to police custody and it is not known whether anyone was killed as a result of the incident.

Parity

In 1957, Chien-Shiung Wu et al. revealed that the -decay process broke parity, showing that nature has a hand. As part of the Wu experiment, radioactive ^{60}Co nuclei were aligned by cooling the source to low temperatures in a magnetic field. According to Wu, more β-rays were released in the opposite direction of the nuclear spin. This asymmetry breaks parity conservation. Suppliers Argentina, Canada and Russia are the largest suppliers of cobalt-60 in the world.

Americium

Americium-241 (241Am, Am-241) is an isotope of americium. Like all isotopes of americium, it is radioactive, with a half-life of 432.2 years. 241Am is the most common isotope of americium as well as the most prevalent isotope of americium in nuclear waste. It is commonly found in ionization type smoke detectors and is a potential fuel for long-lifetime radioisotope thermoelectric generators (RTGs). Its common parent nuclides are β− from 241Pu, EC from 241Cm, and α from 245Bk. 241Am is fissile and the critical mass of a bare sphere is 57.6–75.6 kilograms and a sphere diameter of 19–21 centimetres . Americium-241 has a specific activity of 3.43 Ci/g (curies per gram or 126.8 gigabecquerels (GBq) per gram). It is commonly found in the form of americium-241 dioxide ($241AmO_2$). This isotope also has one meta state, 241mAm, with excitation energy of 2.2 MeV and a half-life of 1.23 μs. The presence of americium-241 in plutonium is determined by the original concentration of plutonium-241 and the sample age. Because of the low penetration of alpha radiation, americium-241 only poses a health risk when ingested or inhaled. Older samples of plutonium containing plutonium-241 contain a buildup of 241Am. Chemical removal of americium-241 from reworked plutonium (e.g. during reworking of plutonium pits) may be required in some cases.

Small button containing $^{241}AmO_2$ from a smoke alarm	
General	
Symbol	^{241}Am
Names	americium-241, Am-241
Protons	95
Neutrons	146
Nuclide data	
Natural abundance	0 (synthetic)
Half-life	432.2 years
Parent isotopes	^{241}Pu (β^-) ^{241}Cm (EC) ^{245}Bk (α)

Decay products	^{237}Np
Isotope mass	241.056829144 u
Spin	5/2−
Excess energy	52936.008 keV
Binding energy	7543.272 keV
Decay modes	
Decay mode	Decay energy (MeV)
α-decay (alpha)	5.486
γ-emission (gamma)	0.0595409
CD (cluster decay)	93.923
Isotopes of americium Complete table of nuclides	

Nucleosynthesis

There have been several kilos of 241Am collected over the years from the small-scale production of americium-241 in nuclear reactors during the past few decades. Despite this, the price of ^{241}Am has remained nearly constant since it was initially put on the market in 1962 because of the difficulty of the separating process.

As Americium-241, plutonium isotope ^{239}Pu is used instead of uranium, which is the most common reactor fuel. The first step is to create the latter, which can be accomplished using the following nuclear process:

$$^{238}\text{U} \longrightarrow {}^{239}\text{U} \longrightarrow {}^{238}\text{Np} \longrightarrow {}^{239}\text{Pu}$$

The capture of two neutrons by ^{239}Pu (a so-called (n,γ) reaction), followed by a β-decay, results in ^{241}Am:

$$^{239}\text{Pu} \longrightarrow {}^{241}\text{Pu} \longrightarrow {}^{241}\text{Am}$$

In spent nuclear fuel, around 12 % of the plutonium includes ^{241}Pu. In order to extract ^{241}Pu, it must be converted to ^{241}Am. However, the decay of ^{241}Pu to ^{241}Am takes a long time: half of the initial quantity decays to ^{241}Am in around 14 years, and the 241Am amount reaches a maximum in 70 years.

It is possible to produce heavier americium isotopes using ^{241}Am in a nuclear reactor by additional neutron capture. Neutron captures on ^{241}Am in a light water reactor (LWR) transform 79 % of the neutrons to ^{242}Am and 10 % to ^{242m}Am.

$$79\%: \quad {}^{241}\text{Am} \longrightarrow {}^{242}\text{Am}$$

Decay

Americium-241 decays mainly through alpha decay, with a weak gamma ray byproduct. The α-decay is shown as follows:

$$^{241}\text{Am} \longrightarrow {}^{237}\text{Np} + {}^{4}\alpha^{2+} + \gamma\ 59.5409\ \text{keV}$$

There are three distinct α-decay energies: 5.486 MeV for 85% of the time, 5.443 MeV for 13% of the time, and 5.388 MeV for the remaining two percent of the time. While other energies such as 13.9, 17.8, and 26.4 are also present, they make up less than one percent of total energies in the majority of the -rays. With a branching ratio of 3.61012, Americium-241 undergoes spontaneous fission, which occurs 1.2 times

every second for every kilogram of 241Am in the universe. As written (with an asterisk denoting a charged atom), it's as follows:

$$^{241}\text{Am} \longrightarrow {}^{241}\text{Am} \longrightarrow 3\text{: n + fission products + energy } (\gamma)$$

americium-241's ^{34}Si cluster decay has a branching ratio of less than 7.41016, making it one of the rarest decays. The way it's worded is as such:

$$^{241}\text{Am} \longrightarrow {}^{207}\text{Tl} + {}^{34}\text{Si}$$

Applications

Ionization-type smoke detector

There has only ever been one synthetic isotope that has made its way into the home, and that is ^{241}AmO2 (americium-241 dioxide), which is used as the source of ionizing radiation in the most common form of smoke detector (the ionization-type), which is the most frequent type of smoke detector. This isotope is chosen over 226Ra because it emits five times the amount of alpha particles while emitting only a small amount of potentially dangerous gamma radiation. With a half-life of 432.2 years, the americium in a smoke detector degrades and contains approximately 3 percent neptunium after 19 years and approximately 5 percent neptunium after 32 years, depending on the model. With an activity of 1 microcurie, the amount of americium in a typical modern smoke detector is 0.29 micrograms (approximately one-third the weight of a grain of sand), which is a small amount (37 kBq). Some older industrial smoke detectors (particularly those manufactured by the Pyrotronics Corporation) can contain as much as 80 Ci of carbon monoxide. 241Am's abundance decreases gradually as it decays into neptunium-237, a distinct transuranic element with a far longer half-life than 241Am (about 2.14 million years). In order to pass through an ionization chamber, which is an air-filled space between two electrodes, the radiated alpha particles must pass through a capacitor plate, which allows a small, constant electric current to pass between the capacitor plates as a result of the radiation ionizing the air space between the plates. Whenever smoke is introduced into the chamber, it prevents some of the alpha particles from readily going through and

reduces the ionization, which results in a decrease in the current. The alarm's circuitry recognizes this dip in current and, as a result, activates the piezoelectric buzzer, which sounds for a short period of time. Ionization smoke detectors are less expensive than optical smoke detectors and are capable of detecting particles that are too tiny to cause substantial light scattering, compared to optical smoke detectors. It is, on the other hand, more disposed to false alarms.

Manufacturing process

The production of americium dioxide, which is utilized in the buttons of ionization-type smoke detectors, is the first step in the production of americium. Prior to being shaped into a briquette and fused under pressure and heat at temperatures in excess of 1,470 degrees Fahrenheit, the AmO_2 is completely mixed with gold (800 degrees Celsius). A silver backing and a gold front coating (or an alloy of gold and palladium) are applied to the briquette and sealed in place using hot forging techniques. This material is then processed through a series of cold rolling steps in order to achieve the required thickness and radiation emission levels for the briquettes. Final thickness is approximately 0.008 inches (0.20 mm) after finishing, with the gold cover accounting for approximately one percent of the total thickness. The final foil strip is approximately 0.8 inches (20 mm) wide and 39 inches (1 m) long, and it is divided into sections that are each 39 inches (1 m) long after it has been cut. The sources are punched out of the foil strip with a hole puncher after it has been folded in half. Typically, the diameter of each disc is around 0.2 inches (5.1 mm), and it is held in place by an aluminum-alloy metal holder that holds the discs in place. The holder refers to the housing, which is the majority of what is visible on the button and contains the majority of the components. The disc is completely sealed around the cut edge of the disc when the disc holder is rolled over on itself. (See the accompanying illustration.)

RTG (radioisotope thermoelectric generator) power generation

It has been proposed for use in radioisotope thermoelectric generators, which could be used in spacecraft, because 241Am has a half-life that is approximately equal to that of ^{238}Pu (432.2 years versus 87 years). This is because 241Am has a half-life that is approximately equal to ^{238}Pu (432.2 years versus 87 years). Despite the fact that americium-241 produces less heat and electricity than plutonium-238 (the power

yield for ^{241}Am is 114.7 mW/g compared to 390 mW/g for ^{238}Pu) and that its radiation poses a greater threat to humans due to gamma and neutron emission, it has advantages for long-duration missions due to its significantly longer half-life. European Space Agency is working on the development of americium-241-based RTGs for space probes as a result of the worldwide scarcity of plutonium-238 and the easy availability of americium-241 in Europe as a result of nuclear waste reprocessing.

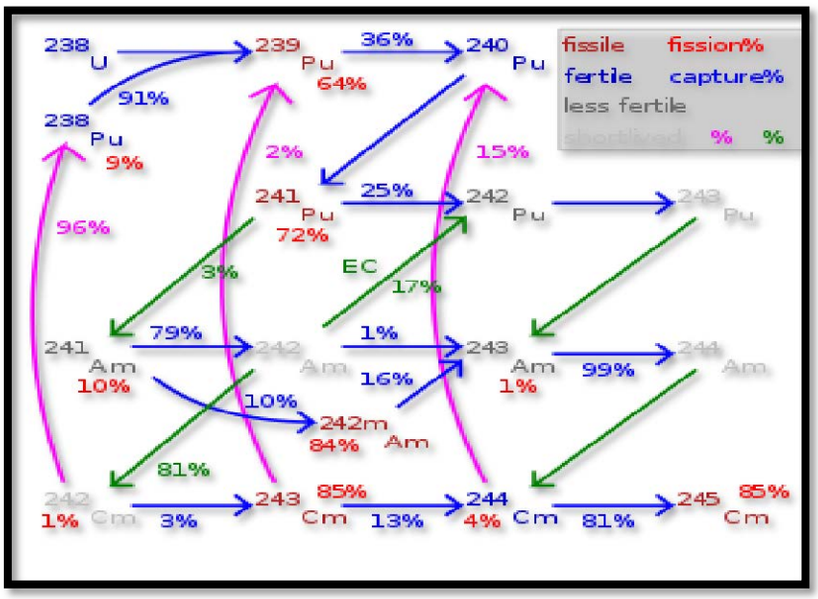
It has the second lowest shielding needs of all conceivable isotopes in an RTG, with only ^{238}Pu having a lower requirement. The fact that ^{238}Pu is produced as nuclear waste and is virtually isotopically pure gives it an advantage over other isotopes. For 5–50 We RTGs, prototype designs of ^{241}Am RTGs anticipate 2–2.2 We/kg, placing ^{241}Am RTGs on par with ^{238}Pu RTGs in that power range.

Neutron source

Because they produce alpha particles after radioactive decay, 241Am oxides pressed with beryllium have the potential to be extremely efficient neutron sources: The alpha source in this case is americium, while the neutron producer is beryllium, which

produces neutrons due to its wide cross-section for the (α,β) nuclear reaction:
Neutron probe are the most common application for ^{241}AmBe neutron sources. A neutron probe is a device that is used to assess the amount of water contained in soil, as well as moisture and density, for the purpose of quality control in highway building. Well logging applications, neutron radiography, tomography, and other radiochemical investigations make use of ^{241}Am neutron sources, as do other radiochemical research.

Production of other elements



^{241}Am is sometimes used as a starting material for the creation of other transuranic elements and trans actinides ; for example, neutron bombardment of ^{241}Am results in the formation of 242Am:

$$^{241}_{95}\mathrm{Am} \xrightarrow{(n,\gamma)} {}^{242}_{95}\mathrm{Am}$$

From there, 82.7% of ^{242}Am decays to ^{242}Cm and 17.3% to ^{242}Pu:

$$82.7\% \rightarrow {}^{241}_{95}\mathrm{Am} \xrightarrow{(n,\gamma)} {}^{242}_{95}\mathrm{Am} \xrightarrow[16.02\ \mathrm{h}]{\beta^-} {}^{242}_{96}\mathrm{Cm}$$

$$17.3\% \rightarrow {}^{241}_{95}\mathrm{Am} \xrightarrow{(n,\gamma)} {}^{242}_{95}\mathrm{Am} \xrightarrow[16.02\ \mathrm{h}]{\beta^+} {}^{242}_{94}\mathrm{Pu}$$

In the nuclear reactor, ^{242}Am is also up-converted by neutron capture to ^{243}Am and ^{244}Am, which transforms by β-decay to ^{244}Cm:

$$^{242}_{95}\mathrm{Am} \xrightarrow{(n,\gamma)} {}^{243}_{95}\mathrm{Am} \xrightarrow{(n,\gamma)} {}^{244}_{95}\mathrm{Am} \xrightarrow[10.1\ \mathrm{h}]{\beta^-} {}^{244}_{96}\mathrm{Cm}$$

The isotopes ^{253}Es (einsteinium) and ^{263}Db (dubnium) are formed when ^{241}Am is irradiated with 12C or 22Ne ions. To make matters even more interesting, in 1949 the Berkeley group used the same 60-inch cyclotron that had been used for many prior attempts to make berkelium (243Bk isotope) from 241Am. At Russia's Joint Institute

for Nuclear Research in Dubna, numerous reactions involving the irradiation of ^{243}Am with 15N ions yielded nobelium in 1965. In addition, the bombardment of ^{243}Am with 18O was one of the synthesis procedures for lawrencium found by scientists at Berkeley and Dubna.

Spectrometer

Americium-241 has been used in the medical and industrial fields to create portable sources of gamma rays and alpha particles. Nuclear density gauges and nucleoluminescence spectroscopy can be used to perform indirect analyses of materials, and the source's 59.5409 keV gamma ray emissions can be used to perform quality control in nuclear densometers. It has been used to measure the thickness of glass, for example, to aid in the production of flat glass. The spectra of Americium-241 contain only one peak and very little Compton continuum, making it ideal for calibrating low-energy spectrometers (significantly reduced intensity by at least three magnitudes).

Medicine

Americium-241 gamma rays have been utilized to diagnose thyroid function in a passive manner. This medical application has been deemed obsolete and is no longer supported. With a 10-minute exposure time, the gamma rays of Americium-241 can produce radiographs of acceptable quality. Long exposure times, which increase the effective dose to living tissue, have limited the use of 241Am radiography. The "time, distance, shielding" maxim employed in radiation protection is based on the idea that the longer exposure, the more likely it is that ionization events may cause damage to cells and DNA.

Hazards

An americium-241 isotope, like all other americium isotopes, is very poisonous and radioactive. Toxic risks exist for those who consume radioactive emitters, even when the α particles are prevented by a piece of paper. Additionally, Americium and its isotopes have heavy-metal toxicity, making them extremely hazardous to the human

body. ^{241}Am can only be administered to the human body in doses as low as 0.03 Ci (1,110 Bq).

It is a -emitter with a weak -ray byproduct known as americium-241. If you don't know how to handle americium-241 in a safe manner it could be quite harmful. It has a gamma dose constant of 3.14 x 10^{1} mR/hr/mCi or 8.48 x10-^{5} mSv/hr/MBq at a distance of one meter.

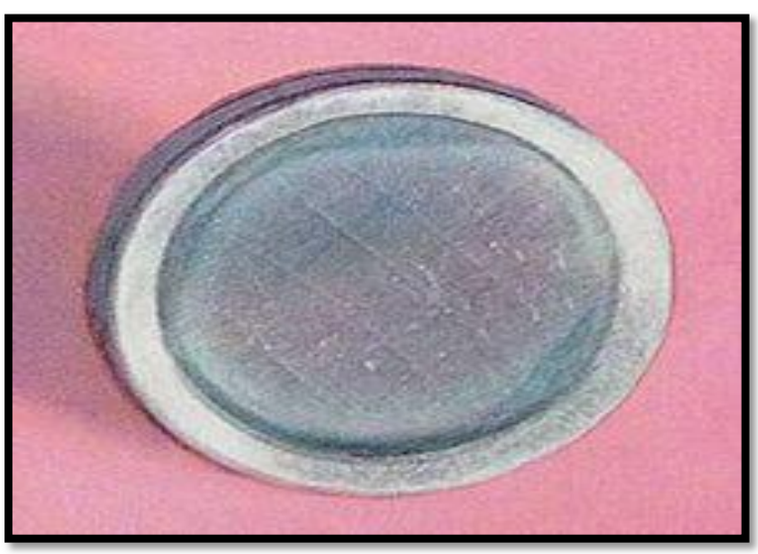
Only 0.05 % of americium-241 gets absorbed into the blood when it is ingested. From there, around half of it is transported to the liver, the other half to the bones, and the final 10 %is expelled. As we get older, our livers take in a greater amount of nutrients. Americium is first deposited on the bone's cortical and trabecular surfaces, and then spreads out over the bone throughout time as it ages. As a result of its radioactivity, americium stimulates the creation of cancer cells in all of these organs due to its biological half-life of 50 years in the bones and 20 years in the liver, but it is permanently present in gonads (testicles and ovaries).

Smoke detectors that have been discarded often contain the radioactive element americium-241. Smoke detectors can be disposed of in most places with no concern for the rules. Americium-241 was obtained from smoke detectors by "Radioactive Boy Scout" David Hahn in the United States, who bought 100 of them at discount prices and then stole a couple. Even though americium-241 has only been found in a few people, the worst example was Harold McCluskey at 64 years old when an explosion in his lab exposed him to 500 times the occupational guideline for this radioactive material. At 75, McCluskey succumbed to an unrelated cardiac condition that had been present before the event.

D-Polonium

This element has the symbol Po and the numeric value of 84. Polonium is a chalcogen, a type of metal. Polonium is a rare and highly radioactive metal with no stable isotopes. It is chemically comparable to selenium and tellurium, but its metallic nature resembles that of its horizontal neighbours in the periodic table: thallium, lead and bismuth. Since it is the penultimate daughter of naturally occurring uranium-238, its only known natural occurrence is in minute amounts of the transient polonium-210 (which has a half-life of 138 days). Even if some longer-lived isotopes exist, they are extremely difficult to create. Currently, milligram quantities of polonium are made by bombarding bismuth with neutrons. Since it's high radioactivity causes chemical bonds to be radioactively broken and its self-healing to occur, its chemistry has been studied mostly in tiny amounts.

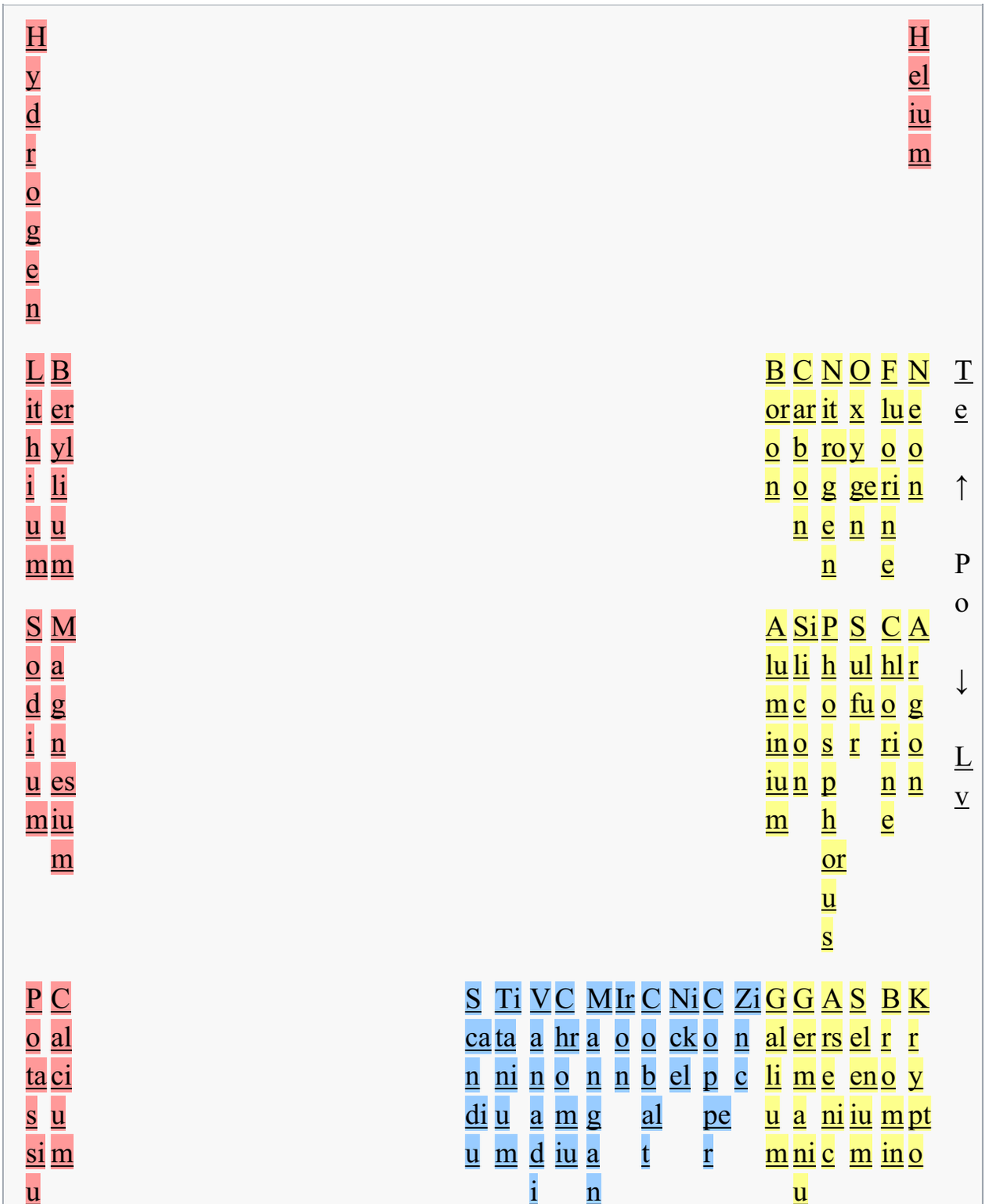
As the first element to be recognized simply by its intense radioactivity, polonium was discovered by Marie and Pierre Curie in July 1898 from the uranium ore pitchblende. After Marie Curie's native Poland, Polonium was given its name. There are just a few uses for polonium because of its radioactivity: heaters in space probes, antistatic devices, neutron and alpha particle producers, and poison. It poses a serious threat to human life.

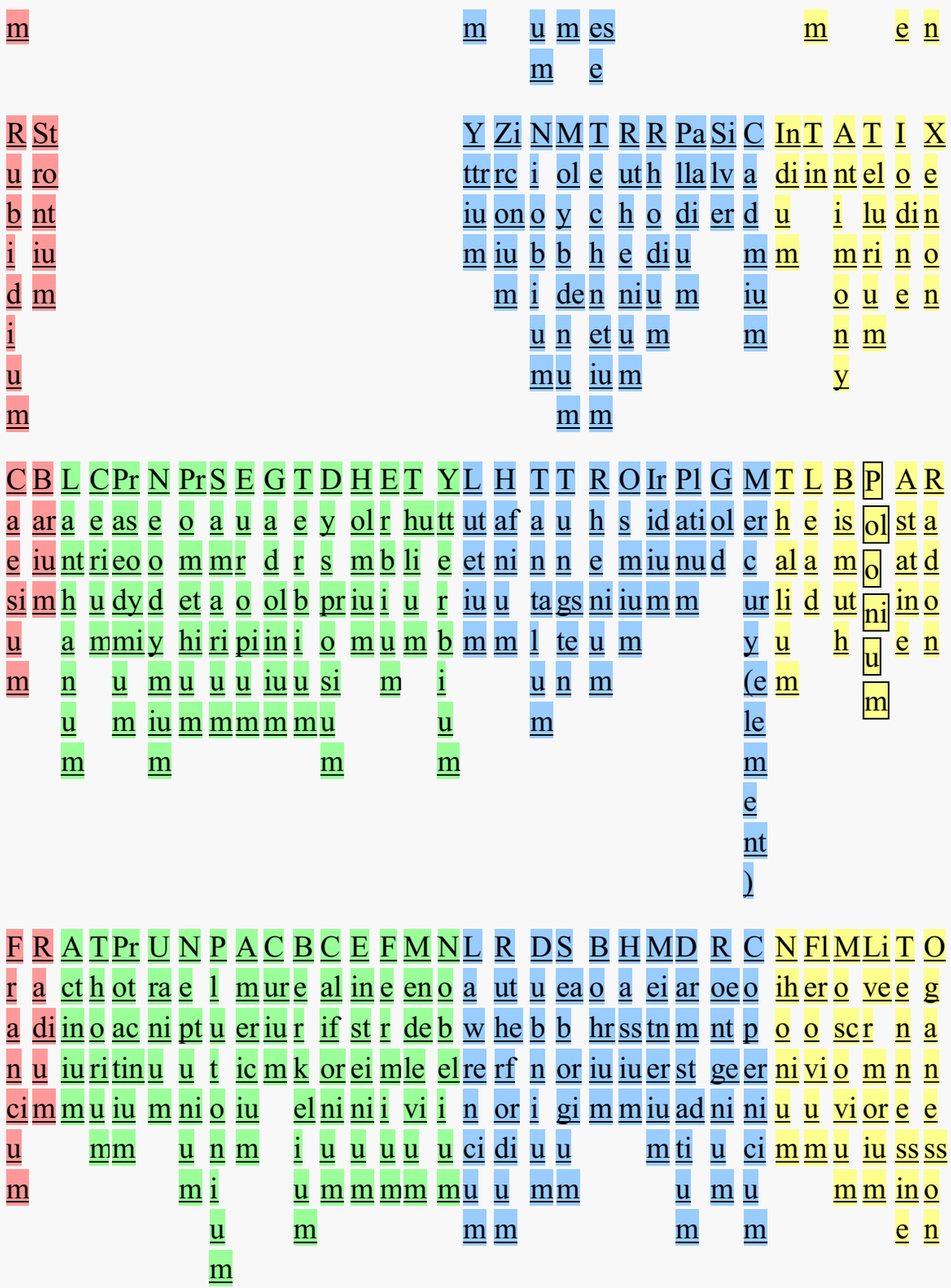


Polonium	
Pronunciation	/pəˈloʊniəm/ (*pə-LOH-nee-əm*)
Allotropes	α, β

Appearance	silvery
Mass number	[209]

Polonium in the periodic table



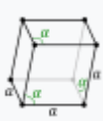


Atomic number (*Z*) 84

Group	group 16 (chalcogens)
Period	period 6
Block	p-block
Electron configuration	[Xe] $4f^{14}$ $5d^{10}$ $6s^2$ $6p^4$
Electrons per shell	2, 8, 18, 32, 18, 6
Physical properties	
Phase at STP	solid
Melting point	527 K (254 °C, 489 °F)
Boiling point	1235 K (962 °C, 1764 °F)
Density (near r.t.)	alpha: 9.196 g/cm^3 beta: 9.398 g/cm^3
Heat of fusion	ca. 13 kJ/mol
Heat of vaporization	102.91 kJ/mol
Molar heat capacity	26.4 J/(mol·K)
Vapor pressure	

P (Pa)	1	10	100	1 k	10 k	100 k
at *T* (K)				(846)	1003	1236

Atomic properties	
Oxidation states	−2, +2, +4, +5,[1] +6 (an amphoteric oxide)
Electronegativity	Pauling scale: 2.0

Ionization energies	1st: 812.1 kJ/mol
Atomic radius	empirical: 168 pm
Covalent radius	140±4 pm
Van der Waals radius	197 pm
	
Spectral lines of polonium	
Other properties	
Natural occurrence	from decay
Crystal structure	cubic
	
	α-Po
Crystal structure	rhombohedral
	
	β-Po
Thermal expansion	23.5 µm/(m·K) (at 25 °C)
Thermal conductivity	20 W/(m·K) (?)
Electrical resistivity	α: 0.40 µΩ·m (at 0 °C)

Magnetic ordering	nonmagnetic
CAS Number	7440-08-6
History	
Naming	after *Polonia*, Latin for Poland, homeland of Marie Curie
Discovery	Pierre and Marie Curie (1898)
First isolation	Willy Marckwald (1902)
Main isotopes of polonium	

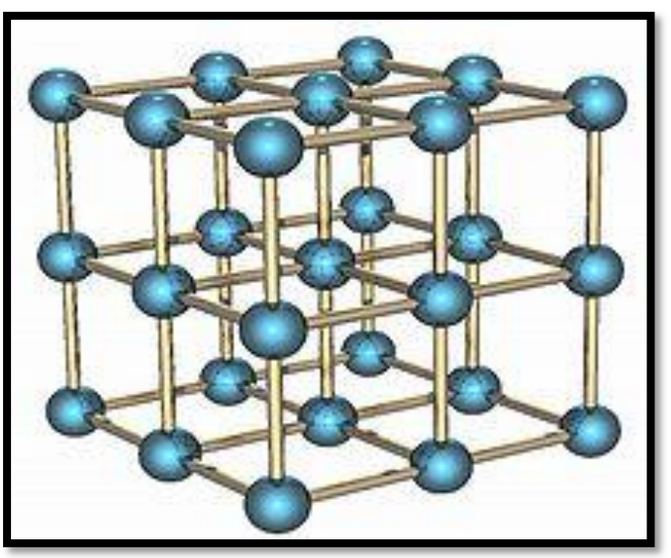
Isotope	Abundance	Half-life ($t_{1/2}$)	Decay mode	Product
^{208}Po	syn	2.898 y	α	^{204}Pb
			β^+	^{208}Bi
^{209}Po	syn	125.2 y[2]	α	^{205}Pb
			β^+	^{209}Bi
^{210}Po	trace	138.376 d	α	^{206}Pb

Characteristics

^{210}Po decays to its stable daughter isotope ^{206}Pb in 138.4 days when used as an alpha emitter. In comparison to 5 grams of ^{226}Ra, 210Po produces approximately the same number of alpha particles per second. The ionization of the surrounding air caused by a few curies of ^{210}Po results in the emission of a blue glow from ^{210}Po. A gamma-ray with a maximum energy of 803 keV is emitted approximately one in 100,000 times by alpha radiation.

Solid state medium

There are two metallic allotropes of the radioactive element polonium. Only the alpha form, It has been discovered on a single atom basis at STP to have an edge length of 335.2 picometers, whereas the beta form has a rhombohedral structure. The structure of polonium has been determined using X-ray diffraction and electron diffraction, respectively. When heated to 55 °C (131 °F), ^{210}Po (like ^{238}Pu) may easily become airborne, with 50% of the sample vaporizing into diatomic Po_2 molecules in 45 hours, despite the fact that polonium's melting and boiling points are both 962 °C (1,764 °F). Polonium has more than one possible explanation for this; one theory is that alpha decay breaks off small clusters of radioactive atoms.



Chemistry

Polonium's chemistry is similar to that of tellurium, although it also shares certain characteristics with its cousin bismuth because of its metallic composition. Acids dissolve polonium more readily than alkalis, but only slightly. Po^{2+} ions give Polonium solutions their pink color, however alpha radiation from polonium swiftly converts them from Po^{2+} to $Po^{4+,}$ resulting in their yellow color. It is imperative that polonium solutions be securely packed to avoid them evaporating within days. It is easy to hydrolyze and complex polonium ions due to their somewhat acidic pH of about 1.

Compounds

Polonium has no naturally occurring compounds, and nearly all of its known compounds were synthesized. Polarides are the most stable polonium compounds because they are formed by the direct interaction of two elements. The polonides of Ca, Ba, Hg, Pb, and lanthanides form a NaCl lattice, but BePo and CdPo have a wurtzite structure and MgPo has a nickel arsenide structure. BePo and CdPo also have lanthanides as their polonides. It is interesting to note that the structure of Na2Po is in fact antifluorite. The exceptions to this rule are lanthanide polonides, which melt at temperatures greater than 1000 °C but do not breakdown at temperatures below 300 °C. At 2200 °C, TmPo melts, but at 1250 °C, PrPo melts. Only one naturally occurring polonium compound, PbPo, is formed when polonium alpha decomposes to lead.

Polonium hydride (PoH_2)

At room temperature, A volatile liquid that is easily dissociated, He is also thermally insensitive. Water is the only other hydrogen chalcogenide known to be a liquid at ambient temperature, however this is due to hydrogen bonding rather than a chemical reaction. The three oxides produced by the oxidation of polonium are designated as PoO, PoO_2, and PoO_3.

The halides of the structures PoX_2, PoX_4 and PoF_6 have been found. Hydrogen halides such as HCl, HBr, and H2O make it possible to dissolve PoClX, PoBrX, and PoI4 in these solvents. $PoCl_4$ and $PoBr_4$ can be directly reacted with each other, or they can be reduced to $PoCl_4$ and $PoBr_4$ with H_2S at room temperature. Polonium dioxide can be reacted with HCl, HBr, or HI to produce tetrahalides.

Potassium polonite is another polonium compound, as well as potassium polonate, polonate acetate and polonate bromate and carbonate as well as citrate chromate and cyanide as well as (II) and (IV) hydroxides, nitrate, selenite, monosulfide, sulfate, disulfate, and sulfite as well as potassium polonite.

Diarylpolonium dihalides (R_2Po) are the only crystalline forms of organopolonium chemistry that have been discovered so far (Ar_2PoX_2). Thiourea is used in the chelation process to form 2,3-Butanediol, which is soluble in water.

Formula	Color	m.p. (°C)	Sublimation temp. (°C)	Symmetry	Pearson symbol	Space group	No	a (pm)	b(pm)	c(pm)	Z	ρ (g/cm^3)	ref
PoO	black												
PoO_2	pale yellow	500 (dec.)	885	fcc	cF12	$Fm\bar{3}m$	225	563.7	563.7	563.7	4	8.94	[27]
PoH_2		-35.5											
$PoCl_2$	dark ruby red	355	130	orthorhombic	oP3	Pmmm	47	367	435	450	1	6.47	[28]
$PoBr_2$	purple-brown	270 (dec.)											[29]
$PoCl_4$	yellow	300	200	monoclinic									[28]
$PoBr_4$	red	330 (dec.)		fcc	cF100	$Fm\bar{3}m$	225	560	560	560	4		[29]
PoI_4	black												[30]

Oxides	Hydrides	Halides
PoO	PoH_2	PoX_2 (except PoF_2)
PoO_2		PoX_4
PoO_3		PoF_6
		$PoBr_2Cl_2$ (salmon pink)

Isotopes

Polonium has a total of 42 radioactive isotopes, all of which have been identified to date. They have atomic masses between 186 and 227 u. Neutron capture of natural bismuth yields ^{210}Po, which has a half-life of 138.376 days. It is possible to make the longer-lived 209Po (half-life 125.23.3 years, longest-lived of all polonium isotopes) and 208Po (half-life 2.9 years) by bombarding lead or bismuth in a cyclotron with alpha, proton, or deuteron radiation.

History

According to Marie and Pierre Curie, polonium's discovery in July of 1898 was called after Marie Curie's native Poland. When it comes to 32, (Latin: Polonia). The country of Poland did not exist as a sovereign state at the time because it was divided

among Russian, German, and Austro-Hungarian empires. When Curie named the element after her home country, she hoped it would raise awareness of the country's inability to self-determination. There is some speculation that polonium is the first element to be associated with a political debate.

Pitchblende radioactivity led the Curies to look for this element as a possible explanation. Even after removing the radioactive isotopes uranium and thorium, pitchblende still had a higher radioactivity level than the two elements combined. The discovery of radioactive elements prompted the Curies to look for others. After separating polonium from pitchblende in July 1898, they also discovered radium in September of that year, five months after that. Polonium was first isolated in 1902 by German scientist Willy Marckwald , who called it "radio-tellurium" since he thought it was a new element. It wasn't until 1905 that it was shown to be the same as polonium.

The Dayton Project of the Manhattan Project produced polonium in the United States during World War II. The 'Urchin' initiator at the center of the bomb's spherical pit was mostly composed of polonium and beryllium. Urchin set off the nuclear chain reaction just as the weapon's prompt-criticality point was approaching, ensuring that the bomb would not go off without a bang. Pulse neutron generators were employed in later US weapons instead of "urchin," which was used in early US weapons. Until after the war, much of the polonium's physics was kept under lock and key. Jusqu'in the 1960s, its employment as a starter was kept under lock and key.

At the University of Rochester between 1943 and 1947, the Atomic Energy Commission and the Manhattan Project funded polonium experiments on five people utilizing the radioactive material. Polonium excretion was studied by giving the subjects between 9 and 22 microcuries (330 and 810 kBq) of the radioactive substance.

Occurrence and production

Polonium is a rare and valuable element in nature due to the extremely short half-lives of all of the isotopes of polonium. The following isotopes have been discovered in traces as decay products: ^{210}Po, ^{214}Po, ^{218}Po, ^{211}Po, and ^{215}Po, and ^{212}Po and ^{216}Po, in the decay chains of 238, 235, and ^{232}Th, and 212Po and 216Po, in the decay chains of ^{238}U and ^{235}U, respectively. In the group, only one isotope, ^{210}Po, has a half-life of more than three minutes, and that is the most stable isotope.

Polonium can be found in uranium ores at a concentration of around 0.1 mg per metric ton (1 part in 10^{10}) which corresponds to approximately 0.2 % of the abundance of radium in uranium ores. The levels found in the Earth's crust are not dangerous in their current forms. Polonium has been discovered in tobacco smoke produced by tobacco leaves that have been fertilized with phosphate fertilizers.

Pollonium extraction from natural sources is time-consuming due to the rarity of the element's naturally occurring abundance. After removing 37 tonnes of radioactive waste from production, scientists extracted 40 Ci (1.5 TBq) of polonium-210 (9 mg) from a single batch that had 40 Ci (1.5 TBq). [51] Irradiating bismuth with high-energy neutrons or protons is now the most common method for obtaining polonium.

When natural 209Bi is blasted with neutrons, 210Bi is generated and then decays to 210Po via beta-minus decay in 1934, an experiment indicated. Liquid-liquid extraction procedures are used after pyrochemical purification to complete the process. Polonium may currently be produced in milligram quantities using this method that takes advantage of nuclear reactors' high neutron fluxes. To put it another way, there are less than 100 grams of polonium produced per year.

Nuclear reactors using liquid metal cooling and based on lead-bismuth, such as the Soviet Navy's K-27, may encounter issues due to this procedure. These reactors must have safeguards in place in case ^{210}Po is accidentally discharged into the coolant.

The polonium isotopes ^{208}Po and ^{209}Po, which have longer half-lives, can be created in a cyclotron by bombarding bismuth with protons or deuterons. Platinum can be irradiated with carbon nuclei to produce other isotopes that are less neutron-deficient and more unstable.

Application

The Soviet Union manufactured polonium-based sources of alpha particles, which were used in nuclear weapons. Attenuation of alpha radiation was used to measure the thickness of industrial coatings.

When subjected to high levels of alpha radiation, ^{210}Po will spontaneously heat to over 500 °C (932 °F), resulting in roughly 140 watts of power. This is why ^{210}Po is used to power thermoelectric generators powered by radioisotopes that use thermoelectric materials to generate heat. A 210Po heat source, for example, was

utilised in the Lunokhod 1 and 2 rovers (1970 and 1973) and the Kosmos 84 and 90 satellites to keep their internal components warm during lunar nights (1965).

Beryllium oxide may convert the alpha particles generated by polonium to neutrons at a rate of 93 neutrons per million alpha particles. In nuclear weapons and oil well inspections, for example, Po-BeO mixes or alloys are utilized as a neutron source. In the Soviet Union, about 1500 of these sources, each with an activity of 1,850 Ci (68 TBq), were used annually.

Before the introduction of coatings, polonium was also employed in brushes or more complex machinery to remove static charges from photographic plates, textile mills, paper rolls, sheet plastics, and substrates (such as automotive). The alpha particles emitted by polonium are responsible for discharging the charges on the surrounding surfaces. Static energy can be neutralized using brushing with up to 500 microcuries (20 MBq) of 210Po as a charge source. Generic licenses allow buyers to acquire devices that include no more than 500 Ci (19 MBq) of (sealed) 210Po per unit, which can be purchased in any amount. Substitutes for Polonium, a radioactive material with a limited half-life, are widely used in these devices.

The NRC and other regulatory agencies do not require licensing for small amounts of ^{210}Po used in the laboratory and for educational purposes. These small amounts, typically of the order of 4–40 kBq (0.11–1.08μ Ci), are typically used in sealed sources with the polonium being deposited on a substrate or in a resin or polymer matrix, and are not considered hazardous. To make ^{210}Po available for sale to the general people in the United States, small amounts are made and sold by scientific supply firms as "needle sources" for laboratory testing. Polonium is a layer of plating that is then plated with a substance such as gold, which allows alpha radiation (used in studies such as cloud chambers) to pass through while keeping the radioactive material from being released and posing a health risk. As reported by United Nuclear, the company normally sells four to eight of these sources every year.

Polonium spark plugs were sold by Firestone from 1940 until 1953, a period during which the metal was considered dangerous. Because polonium has a short half-life and because buildup on the conductors interfered with the radiation that improved engine performance, the benefits of using such plugs quickly faded after approximately a month, regardless of the fact that the amount of radiation emitted by the plugs was insignificant and posed no danger to consumers. With polonium spark plugs, as with Alfred Matthew Hubbard's prototype radium spark plug that came

before them, it was hoped that they would improve ionization of fuel in the cylinder and, as a result, enable the fuel to burn more quickly and efficiently.

Biology and toxicity

Overview

As polonium has the potential to be harmful, it is not used in biological processes. Polionium-210 is roughly 250,000 times more toxic than hydrogen cyanide in terms of mass. (The fatal dose (LD50) of 210Po for an average adult is less than 1 microgram (see below), while that of hydrogen cyanide is approximately 250 milligrams.) When it comes to radioactivity (as an alpha emitter), the biggest danger is that it is extremely difficult to handle in a safe manner. Processing 210Po is extremely hazardous, even in microgram quantities. To ensure that no contaminants are introduced into the environment during the handling process, specialized equipment (such as a negative pressure alpha glove box equipped with high-performance filters), close monitoring, and stringent handling procedures are used. Whether polonium is consumed, inhaled, or absorbed, the alpha particles created by it will cause immediate damage to any organic tissue that is exposed to them. As a result, because the alpha particles do not enter the epidermis, they are not harmful so long as the alpha particles remain outside of the body's tissues. Hands must be protected at all times with gloves that are chemically resistant and undamaged in order to prevent the transcutaneous diffusion of polonium via the skin. Injections of polonium in concentrated nitric acid can infiltrate fast through inadequate gloves (e.g., latex gloves) or can cause damage to the gloves themselves. Polonium is a chemical element that does not have hazardous chemical characteristics. Methylenecobalamin, which is produced by some microbes, has been shown to methylate polonium, according to some reports. Similar to the way that mercury, selenium, and tellurium are methylated in living organisms to form organometallic compounds, this process occurs in the presence of oxygen. Experiments on rats have revealed that just 0.002 to 0.009 % of the polonium-210 that is consumed is excreted in the form of volatile polonium-210, according to the results of the studies.

Acute effects

It is estimated that an acute dosage of 4.5 Sv is the median fatal dose (LD50). 210Po's committed effective dose equivalent 210Po is 0.51 Sv/Bq if eaten, and 2.5

Sv/Bq if inhaled. Dose fatality can be caused by either ingestion or inhalation of doses that are approximately 50 nanograms in size (ng) each. ^{210}Po has the potential to poison 20 million individuals, with 10 million of them dying as a result of one gram of the substance. Due to the shorter half-life of polonium in humans (between 30 and 50 days, prolonged radiation exposure is less harmful than short-term exposure, resulting in lower 210Po toxicity than the estimations above. Even though the lethal dose of 210Po is estimated to be 0.41 mCi, or 0.089 micrograms (μg), it is still an incredibly low amount. One grain of table salt is around 0.06 mg = 60 μg in weight.

Long term (chronic) effects

Long-term mortality from cancer is increased by 5–10 % Sv, in addition to the acute consequences of radiation exposure (both internal and external). Most of the estimated 15,000–22,000 lung cancer fatalities in the United States each year have been traced in part to indoor radon, which contains the isotopes ^{214}Po and ^{218}Po, which are assumed to cause the majority of these deaths. Additional polonium exposure is caused by smoking.

Regulatory exposure limits and handling

Only 1.1 kBq (30 μCi), or 6.8 picograms, of ingested ^{210}Po can be considered a harmful load on the body. About 10 Bq/m3 (3×10^{-10} Ci/m^3) of airborne ^{210}Po can be tolerated in the workplace. The spleen and liver are the primary targets of polonium in humans. Due to the organs' relative small size (150 g for the spleen and 1.3 to 3 kg for the liver), when polonium is concentrated in these areas, the risk to life is higher than the dose that would be received by the whole person if it were distributed evenly throughout the body, as is the case with caesium or tritium, for example (as T2O).

^{210}Po is widely used in industry, and readily available with little regulation or restriction. In the US, a tracking system run by the Nuclear Regulatory Commission was implemented in 2007 to register purchases of more than 16 curies (590 GBq) of polonium-210 (enough to make up 5,000 lethal doses). The IAEA "is said to be considering tighter regulations ... There is talk that it might tighten the polonium reporting requirement by a factor of 10, to 1.6 curies (59 GBq)." As of 2013, this is still the only alpha emitting byproduct material available, as a NRC Exempt Quantity, which may be held without a radioactive material license.

All polonium and its compounds must be handled in a glove box, which must be kept at a slightly higher pressure than that of the glove box to prevent leakage. The radiation from polonium is not adequately protected by gloves made of natural rubber; surgical gloves are required. Natural rubber is less effective than neoprene at blocking radiation from polonium.

Cases of poisoning

20th century

Polonium was injected into four hospitalized patients and orally given to a fifth for research purposes between 1943 and 1947. The AEC and the Manhattan Project financed research like this at the University of Rochester. With the use of more comprehensive data from rats, researchers sought to determine how much polonium is excreted by humans. Experimentalists sought participants who had not been exposed to polonium at work or in a vehicle crash. Every single one of the participants was afflicted with an incurable illness. The polonium excretion was monitored, and an autopsy was performed on the deceased patient to discover which organs absorbed the polonium. People in their 30s and 40s made up the majority of the patients. Chapter 3 of Biological Studies with Polonium, Radium, and Plutonium, National Nuclear Energy Series, Volume VI-3, McGraw-Hill, New York, 1950, describes the studies. Polonium-210 was the most commonly available polonium isotope at the time of the investigation. As far as the DoE factsheet was concerned, there was no follow-up on the subjects involved.

Irène Joliot-Curie may have been the first person to die from the radiation effects of polonium. A sealed polonium capsule detonated on her research table in 1946, exposing her to the radioactive element. She died of leukaemia in 1956.

It is claimed that ^{210}Po was responsible for the deaths of numerous Israelis between 1957 and 1969. Laboratory leaks were found in 1957 at the Weizmann Institute. Toxicologist Dror Sadeh was discovered to have 210Po residue on his hands after an investigation into radioactive materials was conducted. Bone marrow testing was not included in the medical tests, which concluded that there was no danger. Sadeh succumbed to cancer at a young age. Leukaemia claimed the life of one student and cancer claimed the lives of two others he worked with, both within a few years of each other, The investigation was conducted in secret, and no formal acknowledgement was made of a link between the leak and the fatalities.

21st century

When Russian spy Alexander Litvinenko was poisoned to death in 2006, it was found that ^{210}Po poisoning was the cause of death. In an interview with Sky News on December 3, 2006, Professor Nick Priest of Middlesex University, an environmental toxicologist and radiation expert, said that Litvinenko was possibly the first person to die of acute ^{210}Po radiation damage.

Arafat's clothing and personal belongings were found to contain abnormally high levels of ^{210}Po in July 2012, the same month that the Palestinian leader's death was announced. "The clinical symptoms described in Arafat's medical reports were not consistent with polonium-210 and that conclusion could not be drawn as to whether the Palestinian leader was poisoned or not," a spokesman for the Institut de Radiophysique in Lausanne, Switzerland, where those items were analyzed, said. "The only way to confirm the findings would be to exhume Arafat's body to test it for polonium-210." The results of this study were reported in The Lancet on October 12th, 2013. Stains from Arafat's blood, urine, and saliva on his clothes and toothbrush contained higher concentrations of the element than controls. experts from France, Switzerland, and Russia excavated Yasser Arafat's body on November 27th and collected samples for a variety of analyses. The French later discovered polonium in their testing, but they claimed it was of "natural environmental origin." they said. Vladimir Uiba, the chairman of the Russian Federal Medical and Biological Agency, declared in December 2013 that Arafat died of natural causes, and they had no intentions to undertake more tests.

Treatment

It has been suggested that chelation agents, such as British Anti-Lewisite (dimercaprol), can be used to decontaminate humans. In one experiment, rats were given a fatal dose of 1.45 MBq/kg (8.7 ng/kg) of ^{210}Po; all untreated rats were dead after 44 days, but 90% of the rats treated with the chelation agent HOEtTTC remained alive for 5 months.

Detection in biological specimens

Polonium-210 may be detected in biological material by alpha particle spectrometry to confirm a diagnosis of poisoning in hospitalized patients or to offer evidence in a medicolegal death investigation. The baseline urine excretion of polonium-210 in healthy adults due to routine exposure to environmental sources is generally in a range of 5–15 mBq/day. Levels in excess of 30 mBq/day are symptomatic of excessive exposure to the radionuclide.

Occurrence in humans and the biosphere

A byproduct of uranium-238 decay, polonium-210 can be found throughout the biosphere, even in human tissues. Radioactive noble gas radon-222, which has a half-life of around 3.8 days, can diffuse into the atmosphere from the Earth's crust through a sequence of solid intermediates such as radium-226. During its 138-day half-life, the polonium-210 decays into stable lead-206, which is then washed back down to the Earth's surface and into the biosphere.

With help from his colleague Marie Curie, an early French biologist Antoine Lacasagne [fr] demonstrated the specific pattern of polonium uptake in rabbit tissues, with significant amounts in the liver, kidney and testicles. [fr] Sulfur-containing amino acids or related molecules may have polonium substituting for its congener sulfur, which is also in group 16 of the periodic table. Similar patterns of distribution may also be seen in human tissues. Although polonium is a naturally occurring element in all individuals, its levels vary widely between cultures and regions and are especially high among arctic dwellers. This makes it an important part of the natural background dose for all people.

Tobacco

It is believed that polonium-210, a carcinogen found in tobacco, is responsible for a large percentage of all lung cancer cases in the world. It appears that the majority of this polonium is sourced from atmospheric lead-210 deposits on tobacco leaves, which was formed as a byproduct from radon-222 gas decaying into lead-210. Radon-222 appears to be a byproduct of fertilizer-applied radium-226 decay.

Since the early 1960s, polonium has been found in cigarette smoke. Over a 40-year span, some of the world's largest cigarette companies attempted to remove the chemical, but to no avail. The findings were never made public.

Food

Polonium is found in the food chain, especially in seafood.

E- Thallium

Thallium is a chemical element with the atomic number 81 and the symbol Tl. It is a post-transition metal that does not occur naturally. When thallium is separated, it mimics tin, but discolors when exposed to the elements. In 1861, chemists William Crookes and Claude-Auguste Lamy found thallium in sulfuric acid leftovers, separately. Flame spectroscopy, in which thallium creates a noticeable green spectral line, was employed by both. Thallium, from Greek θαλλός, thallós, meaning "green shoot" or "twig", was named by Crookes. It was isolated by both Lamy and Crookes in 1862; Lamy by electrolysis and Crookes by precipitation and melting of the resultant powder. Crookes exhibited it as a powder precipitated by zinc at the International exhibition, which opened on 1 May that year.

The +3 and +1 oxidation states of Thallium are the most common. Unlike the other elements in group 13, this one has a +3 state (boron, aluminium, gallium, indium). Thallium's +1 state, which is far more common than in its preceding family members', is a nod to alkali metal chemistry. In fact, thallium(I) ions are most commonly found in potassium-based ore and are handled by cells' ion pumps in many of the same ways as potassium ions (K+).

Commercially, thallium is derived from heavy-metal mineral sulfide ores, not from potassium ore extraction. Most of the thallium produced is utilized in the electronics sector, while the rest is used in the pharmaceutical business and in the fabrication of glasses and ceramic tiles. Infrared detectors also make use of it. During a nuclear cardiac stress test, thallium-201 (as the soluble chloride TlCl) is a radioisotope employed in minute amounts as an agent.

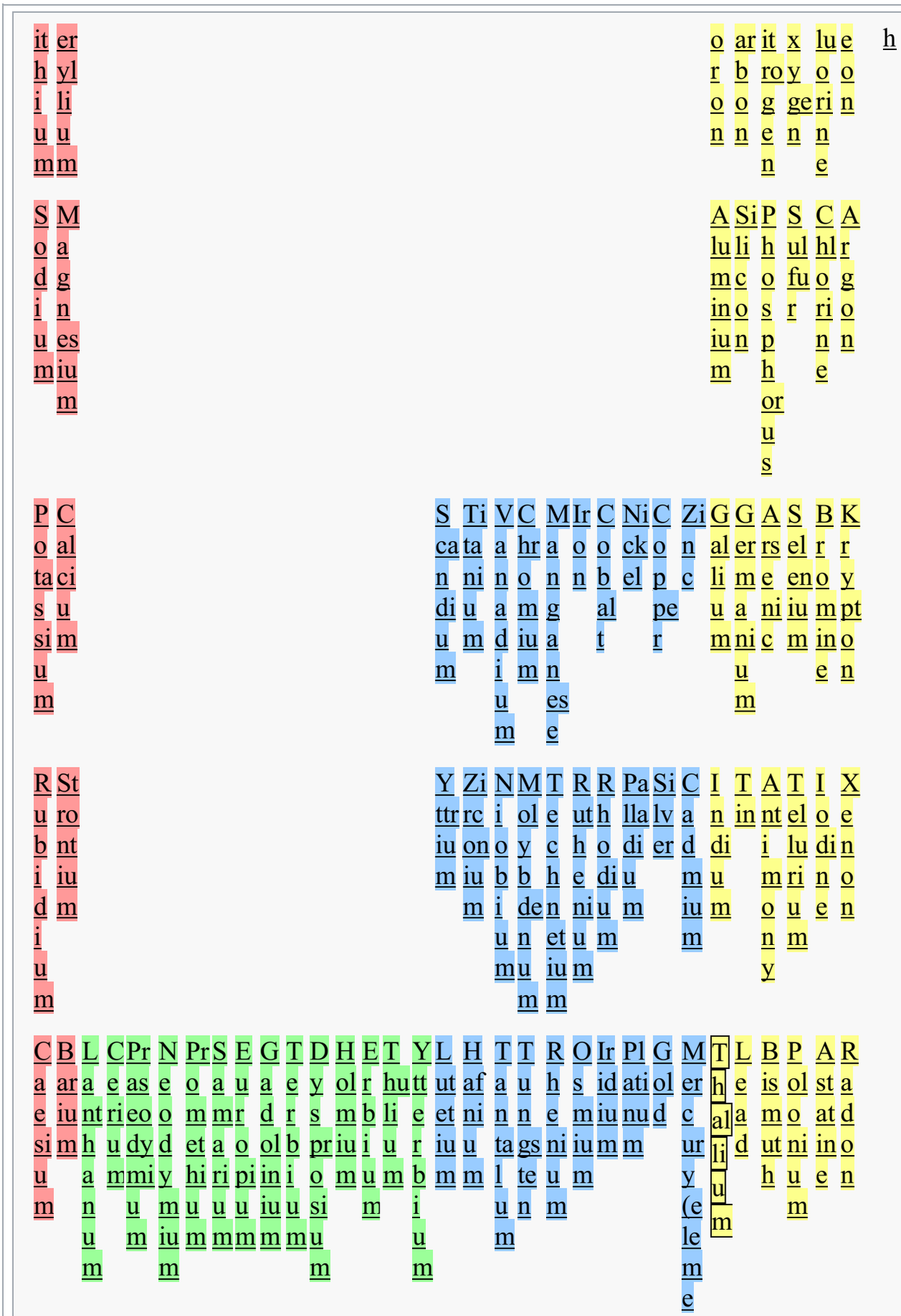
Rat poisons and pesticides have historically contained soluble thallium salts (many of which are practically flavourless). Many countries have banned or restricted the use of these chemicals due to their nonselective toxicity. It is not uncommon for hair loss to accompany thalidomide toxicity; however, this symptom is not always present. thallium has garnered infamy as "the poisoner's poison" and "inheritance powder" because of its long history of use as a murder weapon (alongside arsenic).

Thallium	
Pronunciation	/ˈθæliəm/ (THAL-ee-əm)
Appearance	silvery white
Standard atomic weight $A_{r,\,std}$(Tl)	[204.382, 204.385] conventional: 204.38

Thallium in the periodic table

H																	He
L	B											B	C	N	O	F	N

In
↑
Tl
↓
N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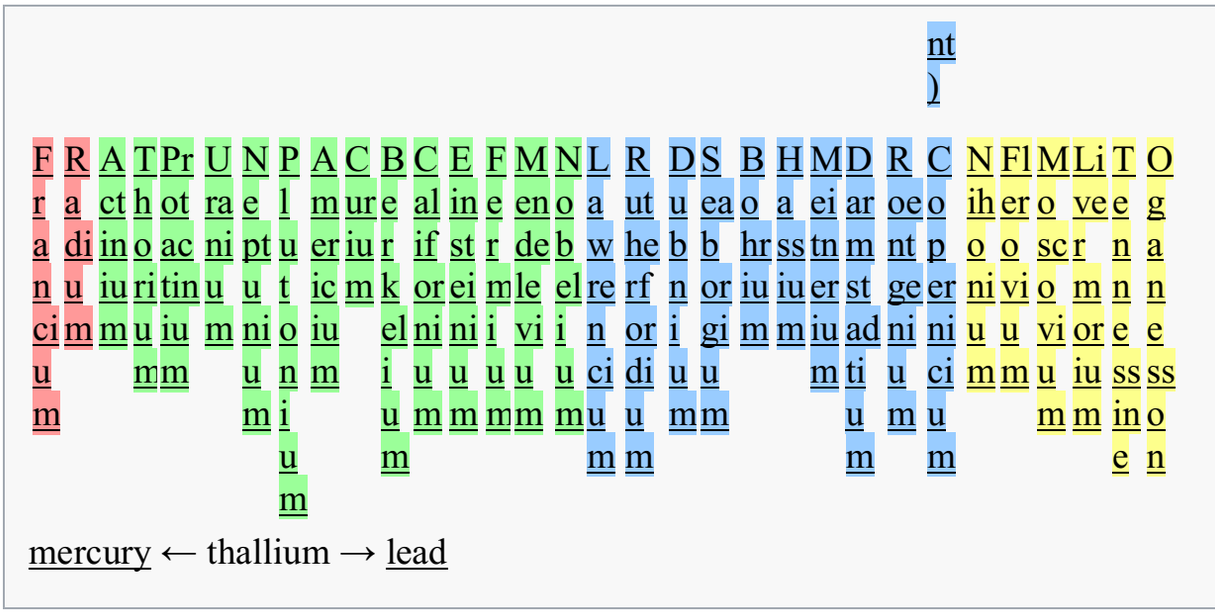
Sodium
Magnesium
Potassium
Calcium
Scandium
Titanium
Vanadium
Chromium
Manganese
Iron
Cobalt
Nickel
Copper
Zinc
Gallium
Germanium
Arsenic
Selenium
Bromine
Krypton
Rubidium
Strontium
Yttrium
Zirconium
Niobium
Molybdenum
Technetium
Ruthenium
Rhodium
Palladium
Silver
Cadmium
Indium
Tin
Antimony
Tellurium
Iodine
Xenon
Caesium
Barium
Lanthanum
Cerium
Praseodymium
Neodymium
Promethium
Samarium
Europium
Gadolinium
Terbium
Dysprosium
Holmium
Erbium
Thulium
Ytterbium
Lutetium
Hafnium
Tantalum
Tungsten
Rhenium
Osmium
Iridium
Platinum
Gold
Mercury (element
Thallium
Lead
Bismuth
Polonium
Astatine
Radon



Atomic number (Z)	81
Group	group 13 (boron group)
Period	period 6
Block	p-block
Electron configuration	[Xe] $4f^{14}\ 5d^{10}\ 6s^2\ 6p^1$
Electrons per shell	2, 8, 18, 32, 18, 3
Physical properties	
Phase at STP	solid
Melting point	577 K (304 °C, 579 °F)
Boiling point	1746 K (1473 °C, 2683 °F)
Density (near r.t.)	11.85 g/cm^3
when liquid (at m.p.)	11.22 g/cm^3
Heat of fusion	4.14 kJ/mol
Heat of vaporization	165 kJ/mol

Molar heat capacity	26.32 J/(mol·K)

Vapor pressure

P (Pa)	1	10	100	1 k	10 k	100 k
at T (K)	882	977	1097	1252	1461	1758

Atomic properties

Oxidation states	−5,[1] −2, −1, +1, +2, +3 (a mildly basic oxide)
Electronegativity	Pauling scale: 1.62
Ionization energies	1st: 589.4 kJ/mol 2nd: 1971 kJ/mol 3rd: 2878 kJ/mol
Atomic radius	empirical: 170 pm
Covalent radius	145±7 pm
Van der Waals radius	196 pm

Spectral lines of thallium

Other properties

Natural occurrence	primordial
Crystal structure	hexagonal close-packed (hcp)

Speed of sound thin rod	818 m/s (at 20 °C)
Thermal expansion	29.9 µm/(m·K) (at 25 °C)
Thermal conductivity	46.1 W/(m·K)
Electrical resistivity	0.18 µΩ·m (at 20 °C)
Magnetic ordering	diamagnetic[2]
Molar magnetic susceptibility	-50.9×10^{-6} cm^3/mol (298 K)[3]
Young's modulus	8 GPa
Shear modulus	2.8 GPa
Bulk modulus	43 GPa
Poisson ratio	0.45
Mohs hardness	1.2
Brinell hardness	26.5–44.7 MPa
CAS Number	7440-28-0
History	
Naming	after Greek thallos, green shoot or twig
Discovery	William Crookes (1861)
First isolation	Claude-Auguste Lamy (1862)

Main isotopes of thallium

Iso-tope	Abun-dance	Half-life ($t_{1/2}$)	Decay mode	Pro-duct
^{203}Tl	29.5%	stable		

^{204}Tl	syn	3.78 y	β⁻	^{204}Pb
			ε	^{204}Hg
^{205}Tl	70.5%	stable		

The electron configuration [Xe]4f^{14}5d^{10}6s^{2}6p^{1} of a thallium atom comprises 81 electrons, three of which are valence electrons in the sixth shell. In comparison to heavier elements, Relativistically stable because of the inert pair effect, the 6s electron pair is less likely to participate in chemical bonding. This metal's low melting point (as low as 304 °C) means that it has a limited supply of electrons available for metallic bonding. As a result, a malleable metal with a low melting point is produced that is also highly electrically conductive.

According to the process under investigation, a variety of standard electrode potentials for thallium have been published, representing the significantly lower stability of the +3 oxidation state:

$$+0.73 \quad Tl^{3+} + 3\,e^- \leftrightarrow Tl$$
$$-0.336\ Tl^{+} + e^- \quad \leftrightarrow Tl$$

This is the first element in Group 13 to allow for the spontaneous reduction of the +3 oxidation state to the +1 state. The bond energies of thallium fall down the group, therefore the energy released in creating two extra bonds and obtaining the +3 state is not necessarily enough to balance the energy necessary to include the 6s-electrons. According to this general pattern of elements, thallium (I) oxide and hydroxide are more basic, while thallium (III) oxide and hydroxide are more acidic.

You can cut through Thallium with a knife at room temperature. When exposed to air, its metallic lustre quickly tarnishes to a bluish-grey hue reminiscent of lead. In order to keep it safe, you can put it in an oil bath. The oxide layer that forms on thallium when exposed to the air is extremely thick and hard. When water is present, thallium hydroxide is created. Thorium is easily dispersed into its sulfate, chloride, and nitrate salts in sulfuric and nitric acids; on the other hand, hydrochloric acid produces an insoluble layer of thallium(I) chloride.

Isotopes

The atomic masses of Thallium's 41 isotopes range from 176 to 216. All of the naturally occurring thallium is composed of only two stable isotopes, ^{203}Tl and ^{205}Tl. This radioisotope has a half-life of 3.78 years, making it the most stable. A nuclear reactor uses neutrons to activate thallium, which is a stable metal. [11][12] By electron capture, the most usable radioisotope, ^{201}Tl (half-life 73 hours), decays. emitting X-rays (~70–80 keV), and photons of 135 and 167 keV in 10% total abundance, therefore, it has good imaging characteristics without excessive patient radiation dose. It is the most popular isotope used for thallium nuclear cardiac stress tests.

Thallium (III)

Compounds of thulium (III) are similar to those of aluminum (III). Their oxidizing power is mild, and their stability is demonstrated by the Tl3+/Tl couple's positive reduction potential. Tl_4O_3 and TlCl2 are two examples of mixed-valence compounds that include both thallium(I) and thallium(II) (III). It is a dark solid that decomposes above 800°C, forming thallium(I) oxide and oxygen. Thallium(III) oxide, Tl_2O_3, Due to the instability of the +3 oxidation state and the limited overlap of thallium's valence 6s and 6p orbitals with hydrogen's 1s orbital, thallane (TlH3), the simplest conceivable compound of thallium, is unable to exist in large quantities. Although they are chemically unique from the lighter group 13 elements, the trihalides are more stable, although they are still the least stable in the entire group. Unlike the lighter group 13 trifluorides, such as thallium(III) fluoride, which forms the TLF_4 complex anion in aqueous solution, TlF3 has a β-BiF3 structure instead. To produce monohalides, the trichloride and tribromide are disproportionately heated over room temperature, whereas the triiodide anion in thallium triiodide makes it an in-fact an isomer of thallium(I). There are no thallium(III) sesquichalcogenides.

Thallium(I)

The halides of thallium(I) are stable. Sodium chloride structures can be found in the chloride and bromide ions due to their relative small size in comparison to the Tl+ cation's massive size. TlCl, TlBr, and TlI are photosensitive and have low water solubility, just like the silver analogs they are modeled after. In contrast to the remainder of the group, thallium(I) compounds are known to be stable oxides, hydroxides, and carbonates as well as several chalcogenides.

It has been discovered that the thallium double salt $Tl_4(OH)_2CO_3$ has hydroxyl-centered triangles of thallium, [Tl3(OH)]2+, as a recurrent motif throughout its solid structure. Thallium ethoxide (TlOEt, TlOC2H5) is a metalorganic molecule with a molecular weight of ρ =3.49 gcm^3 and a melting point of 3 °C. It is frequently employed as a basic and soluble thallium source in organic and organometallic chemistry.

Organothallium compounds

Temperature-dependent properties of organothallium compounds are consistent with the pattern of diminishing thermal stability as one moves down group 13. The Tl–C bond has the lowest chemical reactivity of the group, particularly for ionic compounds of type R_2TlX. Stable in aqueous solution, $[Tl(CH3)2]^+$ ion has a linear structure like $[Hg(CH_3)_2]^{2+}$, which is isoelectronic with $[Pb(CH_3)_2]$. Trimethylthallium and triethylthallium are flammable liquids with low melting points, just like their gallium and indium analogs. Halium(I) is found in the same way as indium in cyclopentadienyl compounds, unlike gallium(I) (III).

History

Thallium (Greek θαλλός, thallos, meaning "a green shoot or twig") was exposed by William Crookes and Claude Auguste Lamy, working independently, both using flame spectroscopy (Crookes was first to publish his findings, on March 30, 1861). The name comes from thallium's bright green spectral emission lines, the enhanced flame spectroscopy method of Robert Bunsen and Gustav Kirchhoff was published Flame spectroscopy became a widely accepted technology for determining the composition of minerals and chemical products with the discoveries of caesium and rubidium between 1859 and 1860. Both Crookes and Lamy adopted the new technique. On selenium compounds deposited in lead chambers of sulfuric acid manufacturing plants near Tilkerode in the Harz mountains, Crookes employed spectroscopic methods to determine the tellurium content. August Hofmann had given him the samples he needed for his research on selenium cyanide years before. He was able to isolate small amounts of the new element and determine the characteristics of a few compounds by 1862, when Crookes was in charge. To evaluate the composition of a selenium-containing material that was formed during the manufacture of sulfuric acid from pyrite, Lamy employed a Crookes-like spectrometer. A green line in the spectrum led him to assume that a new element had been discovered. This by-product, which Lamy had obtained from his friend Fréd

Kuhlmann's sulfuric acid plant, was readily available to him. Starting with that source, Lamy began to separate the new element. As a result of Lamy's ability to work with large quantities of thallium, various compounds' characteristics were determined, and a small metallic thallium ingot was produced by refining thallium acquired from the electrolysis of salts of thallium.

Crookes attempted to establish his own priority on the work because both scientists discovered thallium and a substantial portion of the work, especially the isolation of metallic thallium, was done by Lamy. Lamy won a medal for discovering a new and abundant source of thallium at the International Exhibition in London in 1862 while Crookes was also granted a medal for discovering the new element despite strong protests. The debate raged on between the two scientists for the remainder of 1862 and early 1863. Almost all the debate ended when Crookes was elected a Fellow of the Royal Society in 1863.

The most common usage of thallium was as a rodent poison. In February 1972, following a number of tragic incidents, the use of this substance as a poison was officially outlawed in the United States by Presidential Executive Order 11643 In the years that followed, a number of other countries followed suit.

Occurrence and production

In the Earth's crust, thallium is a modestly abundant element with a concentration estimated to be about 0.7 mg/kg, Potassium-based minerals including clay, soils, and granites are the primary sources of its abundance. However, thallium is not often economically recoverable from these sources. Thallium is most commonly found as a trace element in copper ores, as well as in those of other heavy metal sulfide elements including lead, zinc, and cadmium.

Trace amounts of thallium can be found in the minerals crookesite ($TlCu_7Se_4$), hutchinsonite ($TlPbAs_5S_9$), and lorándite ($TlAsS_2$). Iron pyrite contains traces of thallium, which is removed during the roasting process in order to make sulfuric acid, which is then used in the manufacturing of sulfuric acid as a byproduct.

Smelting lead and zinc ores can also provide thallium, which can be extracted. On the ocean floor, thallium can be found in manganese nodules, but the cost of extracting these nodules has proven prohibitive so far. As a result, the ocean's ecosystem may suffer. There are various different thallium minerals found in nature that range in thallium content from 16-60% and are generally composed of antimony-rich sulfides or selenides, as well as copper-rich thallides or selenides. These minerals

are extremely uncommon and have no commercial value as thallium sources. Thorium was only mined from the Allchar deposit in south-central North Macedonia. Some 500 metric tons of thallium are still thought to be in this deposit, which is also the source of other rare thallium minerals, such as lorándite.

Thallium is produced as a byproduct of smelting copper, zinc, and lead ores, according to the US Geological Survey (USGS). Thallium can either be taken from the smelter flues or the wastes like slag that are collected at the end of the smelting process. A purification process is necessary because the raw materials used to make thallium contain substantial levels of other materials. To remove the thallium, use a base or sulfuric acid on the substance. Remove contaminants from the solution by precipitating the thallium out numerous times By electrolysis on platinum or stainless steel plates, thallium is removed from it at the end between 1995 and 2009, global thallium output declined by 33%, from 15 metric tons to 10 tonnes . We may potentially enhance output by making use of new applications, such as the possibility of an actual thallium-containing high-temperature superconductor, which already exists in small sums and ores with a rather high thallium concentration.

Applications

The odorless and tasteless thallium sulfate was previously commonly employed as a rat poison and ant killer. Since 1972, the United States has restricted the use of this substance due to health and safety concerns. As a result, many countries followed suit. Other skin diseases and tuberculosis patients were treated with Thallium salts, which were also used to alleviate night sweats. Their limited therapeutic range and the introduction of better drugs for certain illnesses have restricted their use.

Optics

Crystals of thallium(I) bromide and thallium(I) iodide have been employed as infrared optical materials because they are tougher than other typical infrared optics and transmit light at much longer wavelengths than those of the others. A brand name for this substance is KRS-5. These glasses are made from Thallium(I) oxide, which has a high refractive index. To produce high-density glasses with melting temperatures between 125 and 150 °C, the combination of sulfur or selenium and arsenic is used. These glasses are robust, insoluble in water, and exhibit distinct refractive indices at room temperature, much like conventional glasses.

Electronic

When exposed to infrared light, the electrical conductivity of Thallium(I) sulfide changes, making this compound a good choice for photoresistors. For infrared detection, thallium selenide has been utilized. To improve the performance of selenium semiconductors, thallium is employed as a doping agent in selenium rectifiers. The sodium iodide crystals used in gamma radiation detectors are another example of thallium doping. As scintillation generators, these crystals of sodium iodide contain a little quantity of thallium. Thallium is used in some dissolved oxygen analyser electrodes.

High-temperature superconductivity

Research into high-temperature superconducting materials for applications such as magnetic resonance imaging, magnetic energy storage, magnetic propulsion, and the

generation and transmission of electric power using thallium is underway. After the 1988 discovery of the first thallium barium calcium copper oxide superconductor, research into applications began. Superconductors with transition temperatures of more than 120 K have been discovered. At ambient pressure, mercury-doped thallium-cuprate superconductors exhibit transition temperatures above 130 K, which is nearly as high as the mercury cuprates that hold the world record.

Medical

Thallium-201, a 73-hour half-life radioactive isotope, was used for nuclear cardiography prior to the widespread use of technetium-99m in nuclear medicine. In individuals with coronary artery disease, the nuclide is still utilized in stress testing to help with risk assessment (CAD). Using a portable generator similar to the technetium-99m generator, this thallium isotope can be produced. Thallium-201 (half-life 9.33 hours) decays from lead-201 via electron capture in the generator. The (p,3n) and (d,4n) reactions can be used to bombard thallium with protons or deuterons in a cyclotron to generate lead-201.

Thallium stress test

In the case of thallium stress tests, the amount of thallium in tissues correlates with the supply of blood to the tissue. Normal Na+/K+ ion exchange pumps are present in cardiac cells that are viable. The Tl+ cation is taken up by the K+ pumps and delivered into the cells. Vasodilation (widening of the arteries) is induced by exercise or dipyridamole in the body. Atherosclerotic plaque builds up in the heart's arteries, making it vulnerable to attack. Infarct or ischemia tissue will stay "cool." Pre- and post-stress thallium may show sites of myocardial revascularization that could benefit. The presence of ischemic coronary artery disease and coronary steal are both indicated by redistribution.

Other uses

Thallium is found to form a eutectic in mercury–thallium alloys, with a freezing point of 60°C, about 20°C lower than mercury's freezing point. Thermometers and low-temperature switches employ this metal alloy as a component. Halium (III) salts

such as thallium trinitrate or triacetate are valuable reagents in organic synthesis for various transformations in aromatics, ketones and olefins, for example. To make the anode plates of magnesium saltwater batteries, an alloy contains thallium as one of its basic elements. Adding soluble thallium salts to gold plating baths helps speed up the plating process and lower the size of gold grains.

Clerici solution is a thallium(I) formate and thallium(I) malonate saturated water solution ($Tl(CHO_2)$ and $Tl(C_3H_3O_4)$). To reduce the concentration of the thallium salts, the colour of the liquid changes from yellowish to colorless. Among the heaviest aqueous solutions, Clerici solution weighs 4.25 g/cm3 at 20 ° C. The severe toxicity and corrosiveness of the solution led to its abandonment as a flotation density measurement method in the 20th century.

Metal-halide lamps typically contain thallium iodide as an addition, generally in combination with one or more other metal halides. For underwater lighting, it can be used to adjust the lamp temperature and color rendering, as well as shifting its spectral output to the green region.

Toxicity

As a result of the toxicity of thallium-containing substances, countless fatalities have occurred. Thallium exposure in a workplace is restricted to a tolerable exposure limit of 0.1 mg/m^2 skin over an eight-hour workday by the Occupational Safety and Health Administration (OSHA). For an 8-hour workday, the NIOSH recommends an exposure limit of 0.1 mg/m^2 for skin exposure, according to the organization's findings. A level of 15 mg/m^2 of thallium poses an immediate risk of death or illness.

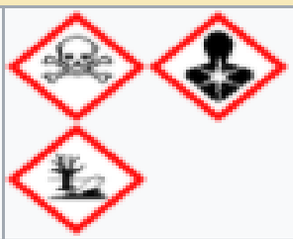
When melting this metal, avoid coming into direct contact with your skin and make sure you have plenty of fresh air to help keep your lungs healthy. In order to avoid cutaneous exposure to Thallium(I) compounds, one must be aware of the fact that cutaneous absorption can exceed the inhalation dose received at the allowed exposure level (PEL). Inhalation exposure should not exceed 0.1 mg/m^2 per hour in an 8-hour time-weighted average (40-hour work week). Some believe that thallium may cause cancer in humans. According to the CDC (Centers for Disease Control and Prevention): "No evidence suggests that thallium can cause cancer, hence it is not classified as a carcinogen. It is not known whether exposure to thallium over a long period of time raises the risk of developmental or reproductive harm. Talc has been linked to nervous system effects, including numbness in the fingers and toes, when

inhaled at high levels." Rat poison made from thallium compounds was widely available for a long time. Accidental or unlawful intoxication due to the fact that the substance is water-soluble and practically tasteless has become a common occurrence.

Prussian blue, a substance that adsorbs thallium, is one of the most used techniques for eliminating thallium from humans. As much as 20 grams of Prussian blue a day is supplied to the patient orally, and it is excreted in the stool. The removal of thallium from the blood serum can also be accomplished by the use of hemodialysis and hemoperfusion techniques. Additional potassium is employed in the therapy later phases to liberate thallium from the tissues.

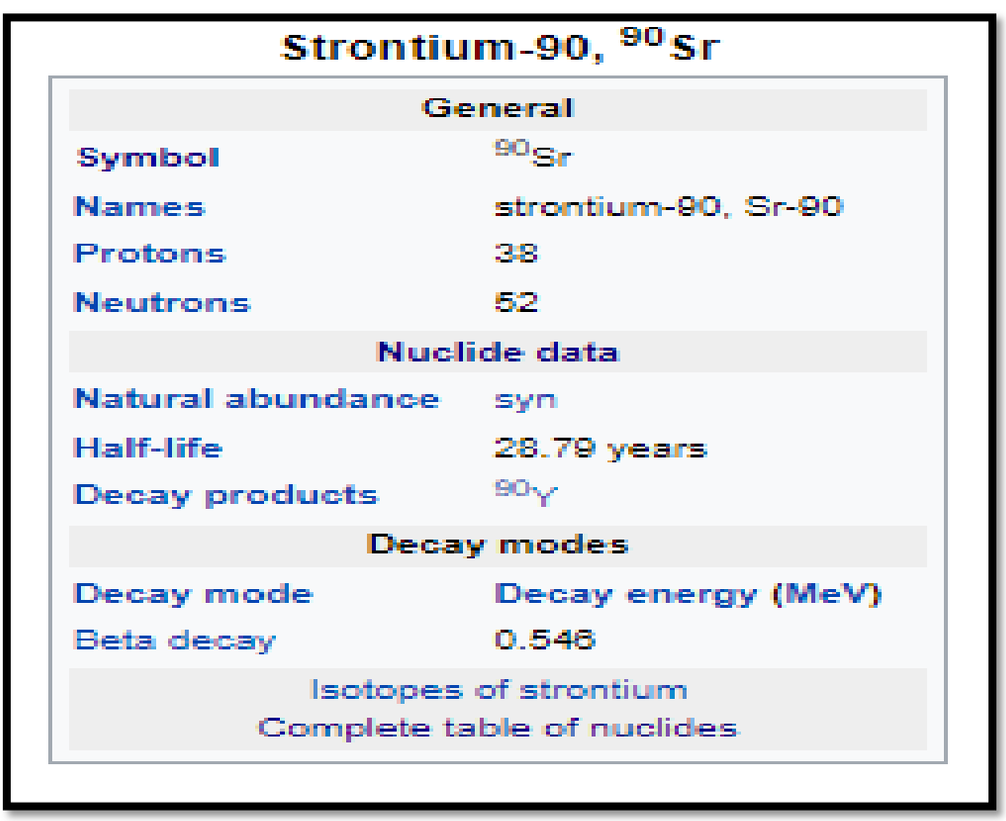
According to the Environmental Protection Agency, man-made sources of thallium pollution include cement industries, coal-burning power plants, and metal sewers. The principal source of high thallium concentrations in water is the leaching of thallium during ore processing.

Thallium

Hazards	
GHS pictograms	
GHS Signal word	**Danger**
GHS hazard statements	H300, H330, H373, H413
GHS precautionary statements	P260, P264, P284, P301, P310, P310[63]
NFPA 704 (fire diamond)	

F-Strontium

Nuclear fission produces strontium-90 (^{90}Sr), a radioactive isotope of strontium with a half-life of 28.8 years. Yttrium-90 is formed via the decay of this nucleus, with a β-decay energy of 0.546 MeV. Strontium-90 is an isotope of concern in nuclear weapon and accident fallout because of its use in medicine and industry.



Strontium-90, ^{90}Sr

General	
Symbol	^{90}Sr
Names	strontium-90, Sr-90
Protons	38
Neutrons	52
Nuclide data	
Natural abundance	syn
Half-life	28.79 years
Decay products	^{90}Y
Decay modes	
Decay mode	Decay energy (MeV)
Beta decay	0.546

Isotopes of strontium
Complete table of nuclides

Radioactivity

Normally occurring strontium is nonradioactive and benign at concentrations commonly seen in the environment, however ^{90}Sr represents a radiation threat because of its radioactive nature. In addition, the stable isotope ^{90}Zr (zirconium) undergoes a half-life of 28.79 years and a decay energy of 0.546 MeV, which is distributed to an electron, an antineutrino, and the yttrium isotope ^{90}Y. In turn, ^{90}Zr (zirconium) undergoes a half-life of 64 hours and a β-decay energy of 2.28 MeV, which is distributed to an electron. It is important to note that 90Sr/Y is nearly entirely a beta particle source; the gamma photon emission from the decay of ^{90}Y is so uncommon that it can usually be ignored when measuring beta particle sources. 90Sr has a specific activity of 5.21 TBq/g.

Medium-lived fission products				
Prop:	$t_{½}$	Yield	Q *	βγ *
Unit:	(a)	(%)	(keV)	
^{155}Eu	4.76	0.0803	252	βγ
^{85}Kr	10.76	0.2180	687	βγ
^{113m}Cd	14.1	0.0008	316	β
^{90}Sr	28.9	4.505	2826	β
^{137}Cs	30.23	6.337	1176	βγ
^{121m}Sn	43.9	0.00005	390	βγ
^{151}Sm	88.8	0.5314	77	β

Fission product

Nuclear fission is the source of ^{90}Sr. A substantial amount of it can be found in nuclear waste, spent nuclear fuel, and radioactive fallout from nuclear reactors. The fission product yield from uranium-235 is 5.7%, from uranium-233 is 6.6%, but from plutonium-239 is only 2.0% for thermal neutron fission, as in today's nuclear power plants.

Nuclear waste

The radioactive isotope strontium-90 is a high-level waste. That's because it's has a 29-year half-life, which means it might take hundreds of years to degrade. Leukemia and bone cancer risk may be increased by use of tainted water and food.

Remediation

Many of the bioremediation plants utilized have no ability to distinguish between calcium and strontium, which means they get saturated with calcium, which is more abundant and also found in nuclear waste.

This algae, Scenedesmus spinosus, has been studied for its ability to bioaccumulate strontium. The study states that S. spinosus has a high strontium biosorption capacity, indicating that it could be suitable for the utilization of nuclear wastes. Closterium moniliform was studied using stable strontium, and it was observed that altering the water barium to strontium ratio increased strontium selectivity.

Biological effects

Biological activity

The next lighter group 2 element, strontium-90, is a "bone seeker" with biological action comparable to calcium. About 70–80 % of the dose is eliminated after it enters the system, most commonly through the intake of contaminated food or water. Only 1% of the remaining strontium-90 is found in blood and soft tissues, with the rest being stored in bones and bone marrow. Toxic to bones, it can also induce cancer of adjacent tissues and leukaemia in people who are exposed to it through their bones. Most typically, urinalysis is used to measure exposure to 90Sr.

It has been estimated that the half-life of strontium-90 in humans can range from 14 to 600 days, 1000 days, 18 years. Strontium's complicated metabolism in the body accounts for the vast range of published biological half-life numbers. However, the entire biological half-life is expected to be approximately 18 years. Due to changes in bone metabolism, age and gender have a significant impact on strontium-90 elimination rates.

As one of the most important isotopes in terms of Chernobyl health effects, it was in the same family as the caesium-based radionuclides ^{134}Cs, ^{137}Cs, and 131I. Primary hyperparathyroidism in Chernobyl workers could be explained by strontium-90

attaching to the parathyroid cells' calcium-sensing receptor, which has a similar affinity to strontium as calcium.

Uses

Radioisotope thermoelectric generators (RTGs)[edit]

For less money than ^{238}Pu, strontium-90 radioactive decay can provide a substantial quantity of heat, 0.95 W/g in pure strontium metal or about 0.256 W/g in strontium titanate. Many Russian and Soviet radioisotope thermoelectric generators employ strontium titanate as a heat source. US "Sentinel" series of RTGs also employed this weaponry.

Industrial applications

Thickness gauges rely on ^{90}Sr as a radioactive source.

Medical applications

Radiation from ^{90}Sr is widely used in the treatment of certain malignancies using surface radiation. Bone cancer can be treated with controlled doses of ^{90}Sr and ^{89}Sr, and coronary restenosis can be treated with vascular brachytherapy using ^{90}Sr and ^{89}Sr. It is also utilized in health and agriculture as a radioactive tracer.

Aerospace applications

In some helicopters with hollow blade spars, ^{90}Sr is utilized as a blade inspection method to show if a crack has appeared.

^{90}Sr contamination in the environment

Because it is less volatile, strontium-90 is less likely than caesium-137 to be released during a nuclear reactor accident, but it is the most hazardous component of radioactive fallout from a nuclear weapon.

There was a significant rise in ^{90}Sr concentrations in the deciduous teeth studied by Dr. Louise Reiss and her colleagues as part of the Baby Tooth Survey during the 1950s and 1960s, according to their findings. Children born in St. Louis, Missouri, in

1963 had ^{90}Sr levels in their deciduous teeth 50 times higher than those reported in children born in 1950, prior to the start of large-scale atomic testing. Study authors projected that persons who ingested strontium-90 will experience an elevated risk of sickness as a result of its fallout. But there have been no follow-up investigations of the subjects, thus the assertion is untested.

John F. Kennedy signed the Partial Nuclear Test Ban Treaty in 1961 after reading an article that contained the study's early findings. This helped persuade him to stop above-ground nuclear weapons testing that released most of the fallout into the atmosphere.

Approximately 10 PBq of strontium-90 was released into the environment as a result of the Chernobyl tragedy, which equates to about 5% of the world's original stockpile. From the time of the accident until 2013, contaminated cooling water from Fukushima Daiichi's reactors emitted between 0.1 and 1 PBq of strontium-90 into the Pacific Ocean.

G-Sodium

From ^{18} Na through ^{39} Na, there are 21 known isotopes of sodium (11Na), as well as the two isomers (22Na and 24Na). ^{23} Na is the only isotope that is both stable and primordial. It has a standard atomic weight of 22.98976928 and is considered a monoisotopic element (2). As it turns out, sodium possesses two radioactive cosmogenic isotopes: 22Na and 24Na, both with half-lives of about 15 hours. All other isotopes have half-lives of less than a minute, with the exception of those two. A half-life of $1.3(4)\times10^{-21}$ seconds makes 18 Na the fastest-acting.

Some of the stable ^{23} Na in human blood plasma is converted to ^{24} Na by acute neutron radiation exposure (e.g., from a nuclear catastrophic accident). This isotope's concentration can be used to calculate the victim's dose of neutron radiation. ^{22} Na is a positron-emitting isotope with a remarkably long half-life. It is used to create test-objects and point-sources for positron emission tomography.

Main isotopes of sodium ($_{11}$Na)

Isotope			Decay	
	abun-dance	half-life ($t_{1/2}$)	mode	pro-duct
^{22}Na	trace	2.602 y	β^+	^{22}Ne
^{23}Na	100%	stable		
^{24}Na	trace	14.96 h	β^-	^{24}Mg

Standard atomic weight $A_{r,\,standard}$(Na) 22.989 769 28(2)[1]

view · talk · edit

Sodium-22

Sodium-22 undergoes positron emission to ^{22} Ne and has a half-life of 2.605 years as a radioactive sodium isotope. In order to manufacture muons for deuterium fusion catalysis, ^{22} Na is being studied as an efficient generator of "cold positrons" (antimatter). It is also utilized in positron annihilation spectroscopy as a positron source.

Sodium-24

As a key isotope, Sodium-24 is a must-have. Neutron bombardment transforms common sodium-23 into this highly radioactive compound. ^{24} Na decays to ^{24} Mg by emitting an electron and two gamma rays within 15 hours of its half-life. Intense neutron flux exposes the organism, resulting in 24 Blood plasma contains a little amount of sodium. This quantity is used to calculate the patient's dose of absorbed ionizing radiation. Determines the level of medical care that is necessary. It takes 24 hours for a nuclear reactor to cool down with the sodium-potassium alloy. A radioactive coolant results from the production of Na. When there are ^{24}Na decomposes, causing magnesium to accumulate in the coolant. There are only 24 hours left in the half-life. Within a few days of being removed from the reactor, all of the coolant's radioactivity is gone forever.

1-3 Effect radiation

The most significant process in the cosmos is the interaction of radiation with matter. When the cosmos began to cool down at an early point of its existence, there were numerous simple molecules present, including water (H_2O), ammonia (NH_3), and methane, which resulted in the development of stars and planets (CH_4). Large hydrocarbons, alcohols, aldehydes, acids, and amino acids were produced in the end as a result of the action of far-ultraviolet light (wavelength less than 185 nanometers) before oxygen appeared in the atmosphere, penetrating alpha, beta, and gamma radiations, and electric discharge from lightning storms when the temperature dropped and water began to condense. The interactions between these fundamental molecules resulted in the formation of living matter. Although it is unclear whether radioactive decay played a role in the synthesis of living matter, microscopic concentric rings known as "pleochroic halos," which are produced by the decay of small specks of radioactive material that emitted penetrating products like alpha pa, have been found in certain micas dating back to very early in the history of the world. Dark rings can be visible microscopically when particles of this type reach the end of their travels. Radioactive matter's composition can be deduced from its ring diameters and penetrating capabilities, which have been measured for alpha particles from a variety of radioactive elements. Other times, the elementary specks that filled the halos' centers weren't those of any currently known elements, ruling out alpha particles as the cause of the phenomena.

As a result of high-energy irradiation to which all matter is subjected, many compounds necessary for life emerged, and some of the elements that contributed to our world's evolution were not present in their original forms, but were created as a result of the aforementioned external bombardment. Therefore, radiation is thought to have played an important role in the evolution of our cosmos and is ultimately responsible for both the presence of life and the diversity of living forms.

Fundamental processes involved in the interaction of radiation with matter

The passage of electromagnetic rays

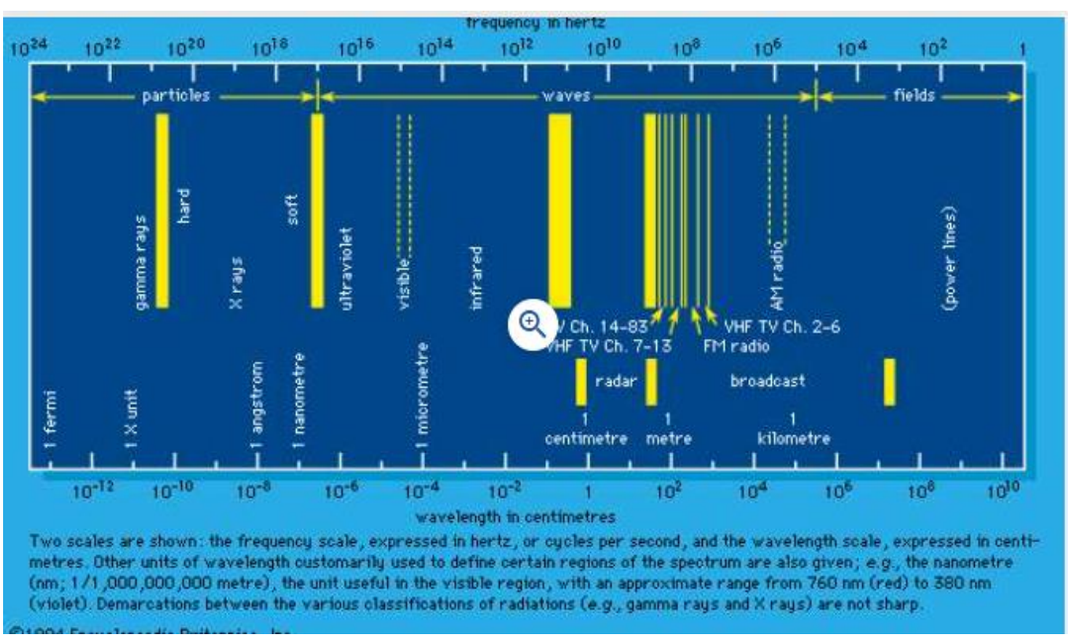
The field concept

To begin, it's necessary to define a few of the more commonly used terminology before moving further with the topic. Every particle, whether it is at rest or in motion,

whether it is charged or uncharged, has potential fields of various kinds surrounding it. As an example, the Earth has a gravitational field surrounding it and around every particle of mass that moves with it. Regardless of where the particle is located, the field has a specific direction. Gm/r2 is the universal gravitational constant multiplied by the square of the distance, r, from a specific particle of mass, m, to calculate the strength of the gravitational field around m at any distance r. As the particle advances, the field expands indefinitely into space and is visible to anybody within the speed of light as it spreads outward. With Newton's work, it was shown that all distances from the center of a homogeneous spherical object are equal. The same is true of the electric fields that surround and move with electric charges. Any point in free space has a magnetic field that is perpendicular to the electric field and changes intensity with any changes in the accompanying electric field. Any regular oscillation, as well as any change in field intensity over time, is time-dependent.

Electric and magnetic fields that are time-dependent exist in conjunction with one another, and when they propagate together, they are referred to be electromagnetic waves. Such waves propagate at the speed of light in an assumed ideal free space (one that is devoid of any other fields or forces of any kind, and, thus, in effect devoid of any intrusions, demarcations, or boundaries), and they do so in the so-called transverse electromagnetic mode, which is a mode in which the directions of the electric field, the magnetic field, and the propagation of the wave are mutually perpendicular. When the thumb and first two fingers of the right hand are perpendicular to each other, a right-handed coordinate system is formed, with the thumb pointing in the direction of an electric field, the forefinger pointing in the direction of a magnetic field, and the middle finger pointing in the direction of propagation, with the thumb and first two fingers of the right hand being perpendicular to each other, and the middle finger pointing in the direction of propagation. Boundary space can be created by applying appropriate physical forces to the space (bound space), or the medium can be something other than a vacuum (other than bound space) (material medium). As a result, new forces and fields are introduced into the equation, and the wave's propagation is no longer limited to the transverse electromagnetic mode alone, as it was previously. It is possible to regard the electric field or the magnetic field (again, this is a matter of personal opinion) to have a component that is parallel to the direction of transmission itself, as shown in Figure 1. This parallel component is responsible for attenuating the energy of waves as they travel through space, and it occurs as waves are propagating.

An large range of frequencies (the number of oscillations per second) is covered by electromagnetic waves, although only a few of them are visible. It's quite unlikely that lower or higher limitations to frequency exist outside of the scope of today's instruments. When discussing electromagnetic waves, it is common to use terms like "frequency" or "wavelength." The frequency ranges to which electromagnetic waves belong are typically designated as fields, waves, and particles in decreasing order of frequency. Fields, waves, and particles (such as gamma-ray photons) are clearly represented in the diagram. Most of the distinctions are of a classical (i.e., nonquantum) nature; in quantum theory, no such distinctions are necessary. For the most part, they've been left intact for historical reasons. Field refers to electromagnetic waves that are larger than the experimental setup in terms of wavelength, but smaller in terms of physical dimensions. Using the wave designation, the wavelength is equal to or less than the size of the physical setup, and the photon's energy is also very low. When the wavelength is small and the photon energy is large, the particle description is useful.



Two scales are shown: the frequency scale, expressed in hertz, or cycles per second, and the wavelength scale, expressed in centimetres. Other units of wavelength customarily used to define certain regions of the spectrum are also given; e.g., the nanometre (nm; 1/1,000,000,000 metre), the unit useful in the visible region, with an approximate range from 760 nm (red) to 380 nm (violet). Demarcations between the various classifications of radiations (e.g., gamma rays and X rays) are not sharp.

Properties of light

To understand the typical features of light, such as the ability to travel in straight lines and the ability to create images using mirrors and lenses, one only needs to know how light propagates, without having to inquire about its nature. It's all about geometrical optics here. It is true, however, that concerns about the nature of light must be answered in order to fully understand its remarkable properties (physical optics). Light has two components: waves and particles. Waves are represented by

the photoelectric effect and particle-based effects like Compton scattering and pair creation. As previously stated, light has a twofold nature. As a result of the dual nature of light and matter, quantum theory was born.

Absorption and emission

Since the light's intensity drops off in a linear fashion as it travels through matter, the fractional loss is the same no matter how far it travels. As a result of this absorption, light's lost energy appears as energy added to the medium. An absorbing material can be both weak and powerful in different regions of the electromagnetic spectrum. As long as the medium has low absorption, the intensity of reflected or transmitted light can be used to assess its dispersion and absorption. On the other hand, light that penetrates even a few wavelengths into something that is substantially absorbing will be completely destroyed. Measuring the reflected or transmitted light is next to impossible because of the low power of the light. However, the absorption and dispersion can still be estimated by observing the reflected light alone in these instances. Refraction and absorption are separated mathematically in the intensity of reflected light, allowing this technique to take place. Molecular activation (see below) is a method for examining absorption in condensed matter in the far ultraviolet, and it has yielded useful insights into electronic energy levels and collective energy losses.

High-intensity, short-duration laser beams have the potential to speed up research into the chemical impacts of radiation on materials. A light source known as the laser, invented by Arthur L. Schawlow and Charles Townes (1958) from the application of one of Einstein's equations, is used to conduct these studies. Using a theory called microscopic reversibility, Einstein hypothesized that the amount of light emitted from excited states of the same molecule system must be dependent on the intensity of the illumination, just as light absorption by a molecular system is. One of the most spectacular examples of the physical consequences of radiation can be found in this critically essential principle of microscopic reversibility.

Specifically, the absorption probability in the ground state is determined by multiplying the number of molecules (or atoms) in that state by both the probability of transition from state I to state j, Bij, and the light intensity, I(v), at a frequency denoted by the Greek letter nu, resulting in the formula Ni Bij I(v) (). In general, the amount of excited-state light emission depends on the number of molecules (or atoms) in the upper state (Nj), multiplied by the probability of spontaneous ground-state emission (Aji), plus the additional induced emission term, Nj Bji I(), where Bji

is a term that Einstein demonstrated is equal to Bij and that relates the probability of such an induced emission, so that, in any steady-state situation, Nj Bji I() is the

$$N_i B_{ij} I(\nu) = N_j [A_{ji} + B_{ji} I(\nu)].$$

A well-developed quantum-mechanical link exists between Aji and Bij, which is not shown here. As a rule, the light intensity, I(v), is so low that the right-hand side of the equation can be overlooked. However, with sufficiently high light intensities, this term can be essential. When the light intensity is strong, as in a laser, the likelihood of induced emission can quickly outweigh that of spontaneous emission. The direction and phase of light that is spontaneously emitted is not predictable. The incident light's polarization and propagation directions match those of the induced emission. There must be enough stimulated emission to offset absorption and scattering if a larger population is formed at the upper level than at the lower one, and this population must then be stimulated by a case light of the right frequency. Laser light is based on this type of stimulated emission. There are three levels of operation for practical lasers such as the ruby and helium-neon lasers.

Particle aspects of light

This is the amount of energy required to remove an orbital electron from an atom or a molecule from its orbital configuration. When light with photon energy greater than the minimum binding energy is absorbed by an atom or solid, the photoelectric effect, the Compton effect, and pair formation all have a part to play, with the relevance of each effect decreasing in order of importance as the photon energy grows higher. When a photon is scattered from an electron, the longer wavelength of the photon causes part of its energy to be transferred to the electron as a result of the scattering. Photons in the other two scenarios are either absorbed or completely destroyed. In order for a photon to be turned into an electron-positron pair, it must first undergo the electron-positron pair-production phenomenon. In its resting state, an electron-positron pair consists of one electron and one positive electron. their entire mass, 2m, times the square of the speed of light ($2mc^2$), requires an energy input of at least 1,020,000 electron volts [eV]. The remaining energy ($h\nu - 2mc^2$) is dispersed between the pair's kinetic energies, with only a small fraction going to nuclear recoil if the photon energy is greater than the rest mass (hv). whose axis is the direction of electron movement.

Energy-transfer mechanism

Until the kinetic energy of a low-velocity electron falls below that of the lowest (electronically excited) state, the electron continues to excite electronic levels in atoms and molecules (see Figure 1). That is when it begins to lose energy as a result of vibrations in the molecules. The employment of transitory negative ion states as an intermediate step in direct momentum transfer collisions is necessary since direct momentum transfer collisions are very wasteful. The loss of energy of electrons with very low energies (less than 1 eV) in a condensed medium is caused by the action of a phenomenon known as phonon emission, as well as interactions with other low-frequency intermolecular motions in the medium (liquid, solid or glass).

At the same speed, the stopping powers of an electron and a single-charged heavy particle are nearly identical. As a result of the electron's modest mass, the relative retardation (reduction in velocity per unit journey length) is substantially greater for it. Electrons, because of their greater slowing down, have a far narrower range if they begin with the same velocity as a heavy particle. When compared to the tracks of a heavy particle, the electrons display far more straggling and scattering. The first effect is due to the electron's ability to shed a big amount of energy in a single interaction; the second is due to its modest mass. As with heavy particles, the index n is slightly less than two when the energy is very high, therefore we may use this relationship as a model for the relationship between range and energy of electrons inside a given medium, which is known as an electric power law. Low-energy systems have a connection in which the exponent is one or less at low energy. If you're looking for a formula or table to determine the stopping power or energy range of electrons or heavy particles, you've come to the right place.

Molecular activation

When radiation interacts with a molecule, the molecule is activated. A wide range of chemical reactions that would not be possible in thermal equilibrium can take place

when the system is in a condition of an abundance of accessible energy. Electron activation, i.e. creating a molecule in an electrically excited state, is critical (see Figure 1). In order to achieve this state, there are three possible routes: first, directly through photon absorption; second, by impacting charged particles and then, either directly or indirectly, through charge neutralization or excitation transfer from excited positive ions; and third, through charge transfer in collision with (relatively) slow incident positive ions. There are numerous processes that take place, and light emission, also known as luminescence, is simply one of them.

Radiation chemical reactions

The role of excitation and ionization in the mechanism of radiation chemical reactions is examined in more thorough studies. Photochemistry provides a wealth of information on the former, but in many cases, the initial excitation process has no meaningful chemical effect at all. ' While this can lead to only a small number of chemical changes, ionization can cause a wide range of other effects, such as ion-molecule interactions, ion-electron fragmentation, and other excited states as a result of charge neutralization. There are a few examples of how these repercussions can be summarized.

Different channels of fragmentation from the same parent ion (*e.g.,* the propane ion $\underline{C}_3H_8^+$), such as

$$C_3H_8^+ \longrightarrow C_3H_7^+ + H \qquad \text{atom elimination}$$

$$C_3H_8^+ \longrightarrow C_2H_5^+ + CH_3 \qquad \text{radical elimination}$$

$$C_3H_8^+ \longrightarrow C_2H_5 + CH_3^+ \qquad \text{radical elimination}$$

$$C_3H_8^+ \longrightarrow C_3H_6^+ + H_2 \qquad \text{molecule elimination,}$$

Competition is permitted unless energy considerations prevent it. Because the ionization potentials of multiple probable fragments can vary substantially, charge localization may only occur on one of them. But because first ionization rarely leads to the positive ion ground state, the energy is usually sufficient for bond breakdown to occur.

Ion-molecule reactions such as that between a water ion and a molecule,

$$H_2O^+ + H_2O \longrightarrow H_3O^+ + OH,$$

Are more important in the condensed phase, and fragmentation is more important in the gas phase. The parent ion in liquid water almost invariably undergoes ion–molecule reaction as indicated above. Many ion–molecule reactions have high cross sections. The same ion may undergo fragmentation or ion–molecule reaction, depending on circumstances. Thus, methane (CH4), acted upon by high-energy gamma radiation, producing an electron, symbolized by $CH_4 \rightsquigarrow CH_4^+ + e^-,$ may be followed by fragmentation, $CH_4^+ \longrightarrow CH_3^+ + H \text{ or } CH_2^+ + H_2,$ as well as an ion–molecule reaction, $CH_4^+ + CH_4 \longrightarrow CH_5^+ + CH_3.$

The electron ejected in an initial ionization process may further ionize and excite other molecules in its path, thus causing other chemical transformations. In addition, it may produce chemical changes of its own by dissociative attachment, as in carbon tetrachloride (CCl_4) and nitrous oxide (N_2O),

$$e^- + CCl_4 \longrightarrow CCl_3 + Cl^-$$

$$e^- + N_2O \longrightarrow N_2 + O^-,$$

And by formation of negative ions of either permanent or virtual (*i.e.,* very short-lived) nature. Many of the negative ions produced in a dissociation process are chemically reactive (H^-, O^-, etc.) as well. Virtual negative ions are almost invariably in a high vibrational state—*i.e.,* they are vibrationally hot.

One thing to remember from this brief review of elementary physical effects and their consequences in radiation chemistry is that each of these effects serves as a seed for a large number of secondary effects, the distribution of which in space depends on the particle's energy as well as the system through which it passes. In photochemistry, there is no counterpart to the concept of quantum yield since there is no one main process that results from the absorption of a single optical photon.

As a rule of thumb in radiation chemistry, yields are expressed in terms of how many molecular species are generated or destroyed for every one hundred eV' of radiation input. Cobalt-60 gamma radiation or electrons of around 2,000,000 eV's energy can be used to radiolyze cyclohexane, and the total yield of hydrogen per 100 eV' input is

commonly quoted as roughly 5.6 or $G(H_2)5.6$, where the letter G is read as "the 100 electron-volt yield of." Occasionally, a small g is used to signify a theorized intermediate's 100-electron-volt yield, which cannot be determined through measurement.

$$H_2O^+ + H_2O \longrightarrow H_3O^+ + OH,$$

Condensed-phase ion-molecule interactions, such as the one between water and water ion, are more important than fragmentation in the gas phase. Ion–molecule reactions are virtually often observed in liquid water, as stated above. High cross sections are common in ion–molecule reactions. Depending on the situation, the same ion can be fragmented or conduct an ion–molecule reaction. As a result, gamma radiation acting on methane (CH_4) may lead to fragmentation and an ion–molecule interaction, as well as the formation of an electron.

$$CH_4 \rightsquigarrow CH_4^+ + e^-,$$

$$CH_4^+ + CH_4 \longrightarrow CH_5^+ + CH_3.$$

$$CH_4^+ \longrightarrow CH_3^+ + H \text{ or } CH_2^+ + H_2,$$

Ionization processes can lead to additional chemical reactions, such as those that result from the release of an electron from an ionization process. Dissociative attachments, such as in carbon tetrachloride (CCl_4) and nitrous oxide (N_2O), as well as negative ions of either a permanent or a virtual nature (i.e., very short-lived) character can induce chemical modifications of their own. Many of the dissociation-generated negative ions (H-, O-, etc.) are also chemically reactive. Almost always, negative ions are in a high vibrational state, which is to say that they are vibrating

$$e^- + CCl_4 \longrightarrow CCl_3 + Cl^-$$

$$e^- + N_2O \longrightarrow N_2 + O^-,$$

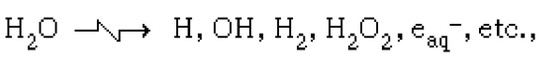
hotly.

One thing to remember from this brief review of elementary physical effects and their consequences in radiation chemistry is that each of these effects serves as a seed for a large number of secondary effects, the distribution of which in space depends on the particle's energy as well as the system through which it passes. In photochemistry, there is no counterpart to the concept of quantum yield since there is no one main process that results from the absorption of a single optical photon.

In radiation chemistry, yields are traditionally stated on the basis of pure empirical calculations based on the number of molecules of a particular kind created (or destroyed) for every 100 eV' of a particular type of radiation applied to the system in question. During the radiolysis (radiation-induced decomposition) of cyclohexane, for example, by cobalt-60 gamma radiation or by electrons with approximately 2,000,000 eV of energy, the overall yield of hydrogen per 100 eV' input is frequently given as approximately 5.6 or G(H2)~ 5.6, where the symbol G is read as "the 100-electron-volt yield of." It is often necessary to use a tiny g to signify the yield of a theorized intermediate that is not immediately determinable by measurement.

Symbolism of radiation chemistry

The symbolism of radiation chemistry is distinct from that of photochemistry. The chemistry is a little more sophisticated, and the formation of the range of beginning chemical reactions is a little more of a chore. When it comes to the action of high-energy radiation on water,



Often, the range of early products is stated by the connection in which is interpreted as "acted with by high-energy radiation, gives" and eaq- is the symbol for the hydrated electron, and is interpreted as "acted with by high-energy radiation, gives". eaq- (that is, an electron solvated by water) is a species that was discovered in the same process and needs special attention. When comparing hydrogen atoms manufactured by typical chemical methods to their atomic counterparts, researchers in water radiation science have known for many years that the hydrogen atom, H, exhibits anomalous behavior. The anomaly was resolved on the one hand by John W. Boag and E.J. Hart, who spectroscopically observed the species eaq- in the spectral region predicted by Platzman, and on the other by Harold A. Schwarz and Gideon Czapski, who demonstrated the existence of the ionic reducing species with charge of minus unity.

Time scales in radiation chemistry

Though it may take a fast electron only 10-18 seconds to traverse a molecule, the time scale characteristic of radiation chemistry can range from the critical completion of some neutralizing processes in extremely viscous environments to the extraordinarily short time scale required for fast electrons to traverse molecules (about three hours). Various events, including the emergence and disappearance of intermediate collections of the various species already addressed, can occur in the interim. A pt scale (in which pt is defined as negative the logarithm, to the base 10, of the time [in seconds] t [i.e., -log10 t]) is used because of the wide range of time scales available. Chemical practice is quite well established when it comes to long-time-scale observations. The short-term region, on the other hand, has its own set of issues. Van de Graaff generator and linear accelerator both allowed for irradiations in the microsecond range (10-6 seconds), and spectroscopic devices were swiftly developed to observe in that region. In the research of luminescence, William P. Helman was able to achieve a precision of 5 $\times 10^{-10}$ second thanks to improvements in the irradiation and observation techniques used by Herbert Dreeskamp, Milton Burton, and Paul K. Ludwig and Juan d'Alessio. Using a linac (linear accelerator) and Cherenkov radiation as a marker, John K. Thomas was able to extend chemical experiments into the same area. A moving electron front (generated by a linac) was used as the light source for spectroscopic observations, which allowed for measurements in the time range of (2 to 4) 10^{-11} seconds.

Tertiary effects of radiation on materials

Further ionizations and the generation of additional electrons are caused by electrons freed by high-energy irradiation. New ionizations are generated by some of the electrons of the second generation, and this process continues until all of the electrons' energy has been used up. There are numerous generations of events that must occur in order for this process to be considered an impact phenomenon in terms of the radiation-induced chemical alterations. Thus, they may be regarded as the most important factors in the overall picture. Radiation-induced chemical changes may be completed in nanoseconds (a nanosecond is 10^{-9} seconds) or less. Dilution-dependent reactions requiring longer reaction times and less reactive scavenger (reagents that remove residue) may need as much as a 10^{-4} second window of time.

On time scales arbitrarily bigger than one minute, this section deals with radiation impacts. Solid state alterations are the focus of this study since there is a lot of

experimental evidence to support these claims. In an atomic medium where the absorption of ionizing radiation also results in structural alterations and caused defects, there is little chemical change expected. Neutron irradiation can "knock off" atoms or ions in addition to causing certain nuclear interactions to occur (Wigner effects in neutrons are discussed in detail above.). As soon as they have captured electrons, they continue on their journey. In spite of the fact that knocked-off electrons may have a tiny effect on ionization and electrical excitation, the neutral knock-offs are believed to have far more significant effects.

Heating effects

Absorption of radiation has as its most basic final result the generation of heat. If the linear energy transfer of low ionizing radiation is small, then the heating impact is not significant. Such low -LET radiation can produce a tiny spherical zone in which the energy deposit is isolated. Since events resulting to heating occur in random sequences, a statistical distribution known as Gaussian may be expected to describe the rise in temperature of the spur over ambient temperature (ΔT). The rise in temperature at a distance r distant from the spur center at time t is described by the equation

$$\Delta T(r,t) = \Delta T_{max}\left(1+\frac{4\gamma t}{a^2}\right)^{-3/2}\exp\left(-\frac{r^2}{a^2+4\gamma t}\right),$$

The initial maximum temperature rise at the center of the spur is given by ΔT max, where an is the initial spur-size parameter and Greek letter gamma, is the medium's thermal diffusivity (heat conductivity divided by the product of density and specific heat at constant volume). For water, we can use a density equal to one gram per cubic centimeter along with a specific heat rate equal to 4 $\times 10^7$ ergs per gram-degree to estimate the maximum temperature to be 30° C (54° F). It takes $(1 + 4t_{1/2}/a2)3/2 = 2$ minutes for the central temperature to fall half its initial value, i.e. $t1_{/2}$. $t_{1/2} = 6\times 10^{-12}$ seconds if the thermal diffusivity, denoted by the Greek letter gamma, is equal to 10-3 centimeter squared per second for water. Because the local temperature change is so modest and transient under low-LET radiation, no chemical or physical effect can be observed. Even while the deposited energy is always used in ionization, dissociation, and related processes, it is noteworthy that the actual temperature rise is less than that calculated here. There is a portion of the energy that is not immediately

available for heating, and it is stored in potential form. With high-LET ionizing radiations, such as fission fragments, stripped nuclei, and -particles, things are a little more complicated. With such a tremendous quantity of energy being deposited per unit path length, the outcome is circular tracks (rather than spherical spurs). If we use this example as an example, the equation for temperature rise is stated similarly to the formula for spur geometry:

$$\Delta T(r, t) = \Delta T_{max} \left(1 + \frac{\gamma t}{a^2}\right)^{-1} \exp\left(\frac{-r^2}{a^2 + 4\gamma t}\right),$$

Other from that, the only differences in this instance are that an is the starting track cylinder size parameter and ΔTmax is the maximum initial temperature rise on its axis. It takes fission pieces of 10-8 centimeters and an an of 20 angstroms to reach ΔTmax in water, with LET equal to 500 eV per angstrom. As with low-LET radiations, this value may be an overestimate, although it is believed that the temperature rise might reach 10,000 degrees Celsius. $T_{1/2}$ = a2/4 calculates the time it will take for the temperature to fall to half of its starting value, which is around 10-11 seconds. This period of time is not much longer than the time it takes for an isolated spur to survive. As a result of the high local temperature, however, the reaction time of the radiation-produced intermediates is likewise quite short. If the activation energy of the reaction intermediate + substrate (i.e. solvent) is eight kcal/mol, the rate constant k for a typical pseudo-first-order reaction can be expressed as follows, using simple chemical kinetics:

$$k \simeq 10^{-11} \exp(-8{,}000/RT) \text{ cubic}$$

centimeter per molecule per second,

The gas constant in units of two calories per degree, and T is the absolute temperature. To get the rate at which the reaction takes place, multiply the number of molecules of substrate per cubic centimeter by 1022 and divide by 10,000. This gives the rate at which the reaction takes place at a temperature of 10,000 degrees Celsius: A "folding" concentration (i.e. fraction 1/E) of the intermediate concentration is achieved in roughly 1.5×10^{-11} seconds, which compares favorably with the duration of the temperature pulse, as seen in this figure. Even while the heat pulse only lasts a short time, it is long enough to speed up interactions between the short-lived intermediates and the ambient substrate.

Surface effects

The physical interaction between a surface and its surrounding environment distinguishes it from bulk matter. When it comes to things like corrosion in salt water or the design of a bearing, the physical state of a surface matters more than anything else. With the application of coatings or radiation, or perhaps both, the latter can be altered. In this article, the effects of ultraviolet curing, ion implantation, and sputtering are examined These are three of the most often used methods of surface alteration involving radiofrequency radiation.

A polymer is cured by ultraviolet light when it is bombarded with the ultraviolet radiation that is used to cure coatings. The long restraint molecules that make up the polymer, either directly or through the mediation of light-sensitive "activators," are excited and ionized as a result. Cross-linking occurs as a result of this intermolecular connection. The entire polymeric covering, generally tenths of millimeters thick (depending on the application), gets so heavily cross-linked that it takes on the character of a single gigantic molecule. UV irradiation of polymers results in a reduction in friction, an increase in hardness, and an increase in resistance to acids and other corrosive substances. There are many applications for ultraviolet curing, from creating "no-wax" coatings on floor tiles to using it in the photolithographic process that is a crucial part of making solid-state electronic devices.

Particle accelerators can produce energetic ions that can be implanted into materials using this technique. The normal level of energy used is 100 keV (100,000 electron volts). Typical penetration depths range from a few thousand angstroms to several thousand angstroms depending on the energy, kind of ion, and target material. It is possible to implant virtually any atomic species at set depths and with predetermined concentration profiles in any target material to alter the surface features without affecting desirable bulk attributes. In order to reduce the amount of wear and tear on bearings and gears, titanium is commonly added to iron alloys. Michael W. Ferralli and Luntz have devised a promising process in which vacuum deposition of polymeric coatings on metallic substrates and ion-beam irradiation simultaneously produce implanted hydrocarbon layers. The carbon-to-hydrogen ratio can be changed from extremely high values—with the implanted region exhibiting certain diamond-like qualities to levels on the order of one and polymeric characteristics. Preferential sputtering is the method employed to achieve this (see below). The films created are very resistant to corrosion and appear to have key bio-compatibility features, making

them appropriate for applications in, for example, the treatment of surgical implants such as artificial hip joints. Some of these effects are due to radiation damage (e.g., making steel's surface amorphous so as to eliminate grain boundaries and other corrosion-sensitive areas), while others are due to chemical bonding between the implanted species and substrate components.

Ion-beam irradiation causes atoms, ions, and molecular species to be expelled from the surface of a target material. Noble (or rare) gases like argon and neon are most commonly utilized in ion implantation because of their high ionization energies. The second method prevents ion-to-substrate chemical interactions that might otherwise occur. Several modes of interaction result in sputtering. Recoil sputtering, in which an incident ion collides with an atom on the surface and causes it to recoil into the target, is conceptually the most straightforward. One of the atoms in the target is ejected from the surface after an elastic rebound collides with the recoiling one. As an example of an analogous but more complicated process, consider recoil sputtering. In this process, an incidentally struck, elastically recoiled surface atom moves through the target material and eventually returns to the surface. There are several ways in which heat spikes near the surface can be released into the atmosphere before they can be used in an annealing process. It is possible that the energy associated with electronic excitations caused by an incident ion can be converted into the atomic recoil kinetic energy necessary to cause ion ejection through the surface of certain materials (such as crystalline alkali halides). There are many other ways to sputter many more atoms than just one for each ion that hits the target using any one of these methods. The sputtering yield is the number of atoms sputtered for each ion that enters the material.

There are four ways in which a material's surface can be changed: structurally (such as the transition from crystalline to amorphous phase), topographically (such as the development of facets and the removal of surface contaminants), electronically (such as radiation-induced chemical changes), or compositionally(such as the alteration of the shape of surface protrusions such as grain boundaries). For example, the development of facets and the removal of surface contaminants are examples of topographical changes that can alter the material's surface (e.g., preferential sputtering of a particular atomic species resulting in changes in the composition of alloys).

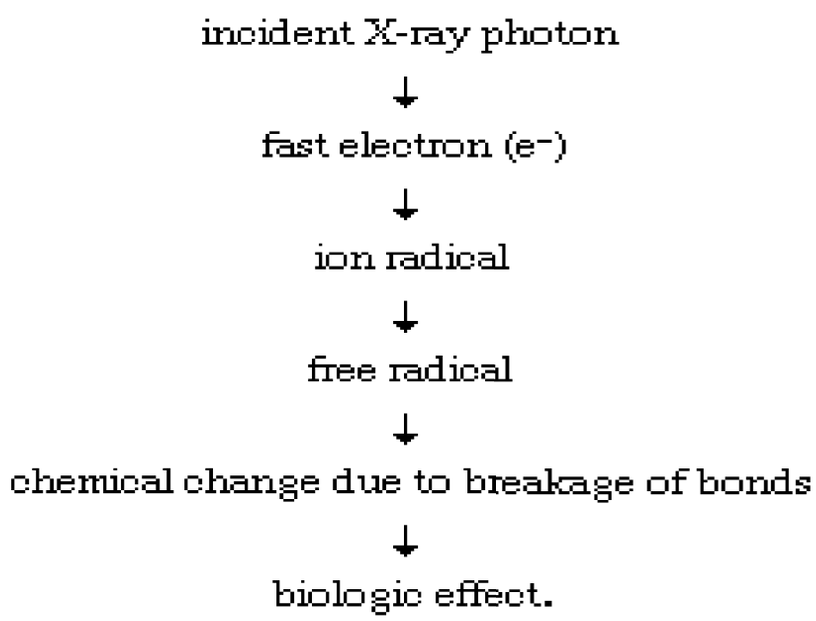
Biologic effects of ionizing radiation

There has been more research into the biological consequences of ionizing radiation than any other environmental component. Many people are concerned about the dangers of low-level irradiation from sources such as radioactive fallout from nuclear weapons, radiation from medical treatments, and waste from nuclear power plants, to name a few.

Knowing how radiation interacts with live cells and the resulting reactions that cause damage is necessary for making an informed decision about ionizing radiation's potential to harm human health. The next sections provide an overview of these topics, focusing on the main environmental radiation sources and levels and the various sorts of biologic impacts that may be connected with them.

Mechanism of biologic action

Radiation from ionizing sources can produce reactive ions and free radicals when they interact with the atoms and molecules in the target area. Ionizations cause molecular modifications and metabolic changes that lead to a wide range of different types of harm. For contrast, X- and gamma-raysexpel "planetary" atomic electrons from their orbits after they receive their energy from the radiation, they are exposed to It's possible to get an electrically charged electron and the uncharged atom from which it's been expelled when an extraterrestrial electron is launched into space. Because of the extremely reactive nature of the free radical formed by the expelled electron, a physiologically significant target molecule could be attacked by the radical before it has had a chance to spread. One way to think about radiation-induced damage caused by free radicals is to consider it as a "indirect action" process.



Depending on the nature of the damage, this could take a long time to complete. Although indirect action is more important than direct action when it comes to low-LET radiation's biological impacts, the latter have a greater ability to cause injury through direct engagement with biological targets (see the passage of matter-rays: Linear energy transfer and track structure above).

The distribution of ionizing atomic interactions along the route of the impinging radiation is dictated by the radiation's energy, mass, and charge. Ionizations produced by neutrons, protons, and alpha particles are more densely packed than those produced by X-rays or gamma rays. Molecular damage produced at a critical site in a cell (such as a gene or chromosome) affects injury probability, and charged particles generally cause more damage to cells than X-rays or gamma-rays for the same total dose administered; in other words, charged particles have a high relative biological efficacy in comparison to these other radiation types. Furthermore (RBE). A radionuclide, or radioactive isotope, that has been deposited within the human body, on the other hand, emits charged particles that can travel only a short distance through tissue before posing a threat to internal organs.

Radioactive fallout and radionuclides

Each radionuclide emits a certain sort of ionizing radiation based on the radionuclide's properties (e.g., electron, positron, alpha particle, gamma-ray, or even distinctive X-ray radiation) Atomic and molecular radionuclides emit a variety of ionizing radiations, including electrons, protons, alpha particles, gamma radiation, and even the highly visible X-ray spectrum. The penetrating strength of a radionuclide's radiation is a significant aspect in assessing whether or not harm would be done if the radiation is exposed to the outside world. Another risk is that of contamination from within. Alpha particles, unlike beta particles or X rays, do not penetrate deep enough into the skin to do harm, unlike powerful beta particles.

Accumulation in critical organs

Ingestion, inhalation, and injection are all methods through which radionuclides can enter the body. Once ingested, the radiation impacts of these substances are determined by their anatomical distribution, time spent in the body, rate of

radioactive decay, and radiation energies. If a radioactive element is deposited inside the body, some organs are more susceptible to radiation than others. It is the thyroid gland where radioiodine accumulates, while radium and strontium are found in the bones. The elimination rates of various radioelements also differ. Even in the absence of radioiodine, the thyroid's content of radioiodine is quickly reduced to half its usual level within days. In contrast, the skeleton retains significant quantities of Strontium-90.

The term "critical organ" refers to the part of the body that is most susceptible to contamination in the context of a specific isotope. Bone and marrow are essential for the production of plutonium, strontium, and radium. The thyroid gland has a unique place in our hearts when it comes to iodine. Insoluble radioactive dust settles in the alveoli of the lungs, whereas colloidal particles can accumulate in the bone marrow, liver, or spleen. There is a risk of harming one's health. Table 9 lists the human exposure limits for various radionuclides based on current U.S. government recommendations. When a radionuclide is present in the body at its highest allowed concentration, there is no significant danger of harm.)

Values for the maximum permissible concentration (MPC) of certain radionuclides

isotope	chemical form	critical organ	mBq in body
tritium (hydrogen-3)	water		$7.4(10^{-3})$
carbon-14	carbon dioxide		$1.5(10^{-5})$
strontium-90*	water-soluble salt		$1.5(10^{-6})$
		bone	$1.5(10^{-7})$
iodine-131	water-soluble salt		$1.8(10^{-6})$
		thyroid	$2.6(10^{-8})$
cesium-137	water-soluble salt		$1.1(10^{-6})$
radon-222**	gas		
radium-226***	water-soluble salt		$7.4(10^{-8})$
		bone	$3.7(10^{-8})$
uranium	water-soluble salt		$7.4(10^{-8})$
		kidney	$1.8(10^{-10})$
plutonium-239	water-soluble salt		$1.5(10^{-8})$
		bone	$1.5(10^{-9})$

*MPC in drinking water: $3.7(10^{-9})$ micro Bq per litre.

**MPC in air: $3.7(10^{-11})$ micro Bq per litre.

***MPC in drinking water: $3.7(10^{-10})$ micro Bq per litre.

This prolonged continuous exposure must be distinguished from a single exposure or repeated exposures because radionuclides continuously release radiation to the surrounding tissue. Studies using divided gamma or X radiation doses have shown that up to 60% of the radiation effect from a single brief exposure can be restored within several hours. As a result, a lower total dose can be tolerated by the body if the dose is taken over time or is absorbed in little amounts over a longer period. However, neutron and alpha radiation have a lower rate of recovery. For a single brief exposure, neutrons are up to eight times more potent agents of mutation than X rays; for chronic irradiation, the advantage can be up to 100 times greater.)

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Chapter

2

Chapter Two/ Radiotherapy

2- Medical applications of radiotherapy

History

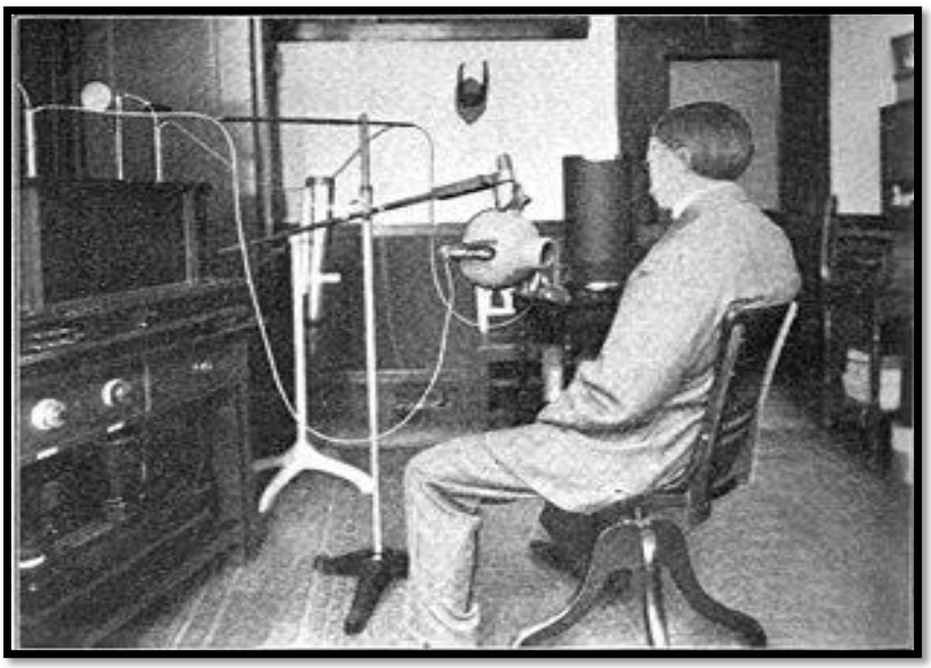
Wilhelm Röntgen's discovery of X-rays in 1895 marked the beginning of the use of radiation treatment as a cancer treatment method for more than a century. Emil Grubbe, a physician in Chicago, In 1896, he may have been the first doctor in the United States to employ x-rays in the treatment of cancer.

Marie Curie (1867–1934), the Nobel Prize winner who exposed the radioactive elements Polonium and Radium, was a key figure in the early development of radiation therapy. Medical research and care have entered a new age. The consequences of radiation exposure were not fully understood in the 1920s, and little shielding was put in place. Due to the widespread use of radium, it was thought that radiation could treat a wide range of disorders.

Before WWII, there was a time when the only effective radioactivity sources were radium, its "emanation," radon gas, and the X-ray tube. X-ray machines had a low maximum power at the turn of the century. (<150 kV) were used to begin external beam radiation (teletherapy). Although low-voltage X-rays could cure superficial cancers, to reach tumors deep within the body, more pervasive, higher-intensity beams were required, which necessitated higher voltage. Radiology began using orthovoltage X-rays in the 1920s, which charity tube voltages ranging from 200 to 500 kV. To reach the deepest tumors minus exposing the surrounding skin and tissue to dangerous radiation levels, "megavolt" radiation was required. Radiation, often known as "megavolt" radiation, measures vital rays with energy of 1 MV or more. M.V X-ray systems were originally created in the late 1930s, then only a few institutions could afford them. Megavolt X-rays required 3 to 5 million volts on the X-ray tube, which necessitated massive, costly installations. The first, which was installed in 1937 and utilized until 1960 at St. “Bartholomew's Hospital in London”, had a 30 foot-long X-ray tube and weighed 10 tons. Due to its low availability in

ores, radium produced megavolt gamma rays but was highly scarce and costly. The global supply of radium for radiation in 1937 was 50 grams, which was worth £800,000 ($50 million in 2005 money). The Manhattan Project's building of a nuclear reactor during World War II made radiotherapy possible. The use of megavolt gamma rays released by cobalt-60, a radioisotope created by irradiating ordinary cobalt metal in a reactor, transformed the area of cobalt therapy between the 1950s and the early 1980s. Cobalt-based machines were quite inexpensive. Because of its 5.27-year half-life, the cobalt had to be replaced every five years.

In the 1980s, medical linear particle accelerators began replacing X-ray and cobalt units, and now these older therapies are diminishing. These accelerators have been produced since the 1940s. In 1953, the Hammersmith Hospital in London became the first medical facility in the world to deploy a linear accelerator. [55] Like radioisotope therapy, linear accelerators may generate larger energy, There will be added collimated beams and no radioactive waste generated in the process. With the advent of computed tomography (CT) by Godfrey Hounsfield in 1971, three-dimensional planning became possible, As a result, the delivery of radiation has shifted from 2-D to 3-D. By using axial tomographic scans of the patient's anatomy, doctors can more accurately calculate the dosage distribution of the patient's anatomy. With the development of new imaging technologies like as magnetic resonance imaging (MRI) in the 1970s and positron emission tomography (PET) in the 1980s, radiation treatment has moved from 3-D conformal to intensity-modulated radiation therapy (IMRT) and image-guided radiation therapy (IGRT). As a result of these advancements, radiation oncologists can better see and target cancers, As a result, treatment outcomes are enhanced, organ preservation is increased, and side effects are reduced. Charge to radiation is improving in high-income nations, In 2017, however, In low- and middle-income countries, it is still unavailable to over half of patients.



Radiation therapy or radiotherapy

Ionizing radiation is used to cure or destroy cancerous cells in the form of a linear accelerator, which is commonly abbreviated RT, RTx, or XRT. Many forms of cancer can be cured by radiation therapy if they are concentrated in a single location of the body. For example, in the early stages of breast cancer, it may be used as adjuvant therapy later surgery to remove a primary malignant tumor. Radiation therapy can be administered before, during, and after chemotherapy in patients with malignancies that are susceptible. Radiation oncology is an oncology specialization focused on radiotherapy. A doctor who specializes in radiation oncology is known as a radiation oncologist.

Radiation therapy is frequently used to treat cancerous tumors because of its effectiveness in slowing down the proliferation of cancer cells. In order to kill cancer cells, ionizing radiation damages their DNA. Shaped radiation beams are focused at the tumor from many exposure angles, producing a significantly higher absorbed dose there than in the surrounding healthy tissue, in order to protect normal tissues such as skin and organs that radiation must pass through in order to treat the tumor. If the tumor is clinically or radiologically engaged with the lymph nodes draining the tumor, or if subclinical malignant dissemination is a possibility, the radiation fields may additionally encompass these lymph nodes as part of the tumor. Because to daily setup and internal tumor movement, there must be a boundary of healthy tissue

surrounding the tumor. Internal movement, such as breathing and bladder filling, and movement of external skin markings relative to the tumor's position, can contribute to these inconsistencies.

Radiation oncology is a medical field concerned with the use of prescription radiation, as opposed to radiology, which is concerned with the use of radiation for medical imaging and diagnosis. For "curative" treatment or adjuvant therapy, radiation can be prescribed by a radiation oncologist. When a cure isn't achievable, it can be used as a palliative treatment (to control the local disease or alleviate symptoms), but it can also be used therapeutically (When the therapy improves survival and has the potential to cure). The combination of radiation therapy with surgery, chemotherapy, hormone therapy or immunotherapy is also prevalent. Radiation therapy can be used to treat the majority of common cancers.

Specific treatment goals will depend on the patient's tumor type (whether it's a primary or metastatic tumor), location, and stage, as well as his or her overall health status. Radiation therapy called "total body irradiation" (TBI) is used to prepare the patient's body for a bone marrow transplant. Brachytherapy, a form of radiation therapy in which a radioactive source is placed inside or near the area to be treated in order to reduce the quantity of healthy tissue exposed during procedures to treat breast, prostate, and other organ cancers. When used to treat non-cancerous illnesses, such as pterygium, pigmented villonodular synovitis (a type of eye inflammation), auditory neuromas, severe thyroid eye disease, and trigeminal neuralgia, radiation therapy offers a wide range of uses. Non-malignant conditions are restricted in their use of radiation therapy because of concerns about the possibility of radiation-induced malignancies.

Medical uses

Radiation therapy has diverse effects on various types of cancer. The radiosensitivity of cancer is a measure of its ability to respond to radiation. Small doses of radiation can quickly kill cancer cells that are particularly radiosensitive. These include leukemias, lymphomas, and tumors of the germ cells. Because most epithelial tumors are only moderately radiosensitive, dramatic remission requires a much greater dosage of radiation (60-70 Gy). A large number of cancers are radioresistant, This means they require higher radiation doses than are likely to be safe in practice. Patients with metastatic renal cell cancer and melanoma are frequently thought to be radioresistant; yet, for many of these tumors, radiation

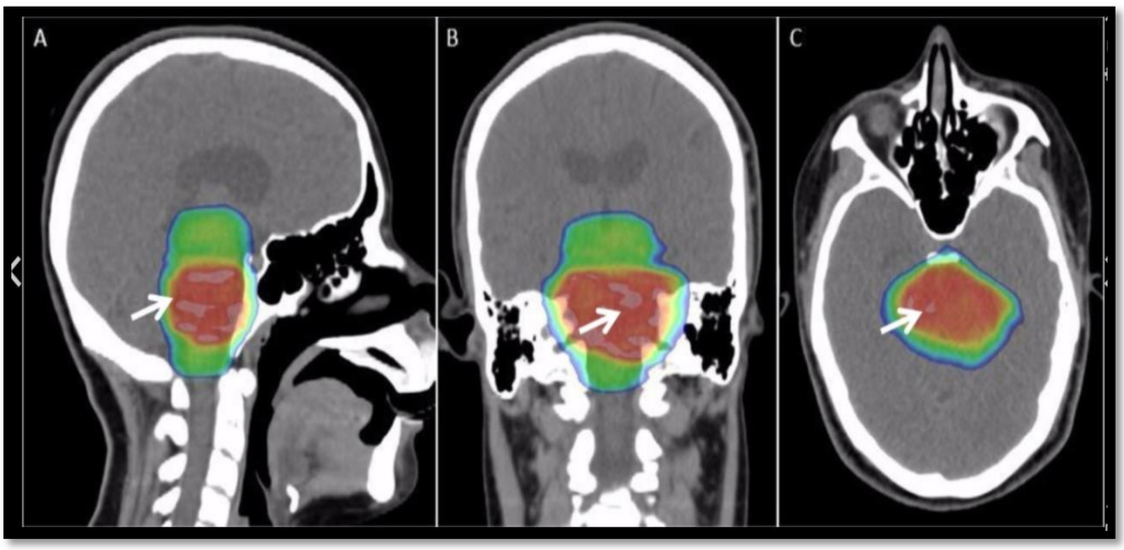
therapy remains a viable treatment choice. Combining radiation therapy and immunotherapy is a contentious topic with some promise in the battle against melanoma and other cancers.

Tumor radiosensitivity should be distinguished from cancer radiation "curability" in actual clinical practice, which is more of a laboratory test than a clinical one. There are some cancers that are not treatable with radiation therapy because they spread throughout the body, such as leukemias. If lymphoma is confined to a single part of the body, it may be possible to treat it regressively. If discovered early in their development, they, Curative radiation therapy is frequently used to treat moderately radioresponsive tumors, as is the case with many other common malignancies. Cancers of the skin, head and neck, breast, non-small-cell lung cancer, cervical cancer, anal tumors, and prostate cancer are only a few examples. Those are all cancers that are not melanoma. There is no cure for metastatic malignancies due to the inability to treat the entire body with radiation treatment.

A CT scan is frequently conducted prior to therapy in order to classify the tumor and any normal structures in its immediate vicinity. Small skin marks are applied to the patient in order to direct the location of the treatment fields. At this stage, the patient's placement is critical since the patient must be located in the same position for each treatment. There are a variety of patient positioning devices available, There are masks and cushions that can be customized to fit the sufferer.

In addition to its size, tumor response to radiation therapy is influenced by this factor. Radiation treatment for large tumors is less effective than radiation treatment for smaller tumors or microscopic illnesses. To counteract this, a variety of tactics are employed. Prior to radiation therapy, surgical resection is the most prevalent method. Breast cancer patients who undergo broad local excision or mastectomy and subsequent radiation therapy are more likely to experience this phenomenon. A different approach is to use neoadjuvant chemotherapy to reduce the size of the tumor before undergoing radiation therapy. As a third approach, certain medications given during radiation therapy can increase cancer's radiosensitivity. Cisplatin, Nimorazole, and Cetuximab are only a few examples of radiosensitizing medications.

The effects of radiation range depending on the type of cancer and the patient's age. For instance, after a breast-conserving procedure, researchers found that radiotherapy cut the recurrence rate in half for patients with breast cancer.



Color-coded radiation therapy is given to a patient with a diffuse intrinsic pontine glioma.

Uses in non-cancerous disease

Radiation therapy is used to treat early stage Dupuytren's and Ledderhose's illnesses. Radiation therapy is recommended as a prophylactic intervention for Dupuytren's disease nodules and cords or finger deformity of less than 10 degrees. In rare circumstances, radiation therapy is done after surgery to stop the disease from progressing. Low amounts of radiation are often used for five days at three grays of radiation, then a three-month break, followed by another five days at three grays of radiation.

Types

Radiation therapy has historically been divided into three types:

Teletherapy or external beam radiation therapy (EBRT or XRT).

Brachytherapy is a type of radiation therapy that uses a sealed source.

• Unsealed source radiation or systemic radioisotope therapy

External radiation is provided from external the body, brachytherapy uses sealed radioactive sources precisely placed in the treatment area, and systemic radioisotopes are administered intravenously or orally. External radiation is provided by sealed

radioactive sources outside the body. Brachytherapy uses radioactive sources that are either temporary or permanent. A technique called as after loading is used to install the temporary sources. After loading, a hollow tube or applicator is surgically implanted in the target organ, followed by the loading of the sources into the applicator. Healthcare workers are exposed to less radiation as a result of this.

External beam radiation therapy

The treatment with x-rays is discussed in the following three sections.

Conventional external beam radiation therapy

In the past, Medical linear accelerators, which produce high-energy x-rays, as well as equipment that looks like a linear accelerator but uses a sealed radioactive source, such as the one seen above, were all used to provide traditional external beam radiation treatment (2DXRT). The treatments consisted of two-dimensional beams. The patient receives radiation from a number of angles, including the front, rear, and both sides. using 2DXRT.

"Conventional" refers to how radiation beams are placed to reach the desired plan in terms of how the treatment is planned on an "x-ray simulator," which is a machine that mimics the operations of a linear accelerator (or sometimes by sight). The goal of the simulation is to correctly pinpoint or locate the treatment area. One of the most widely used methods in the industry. The radiation toxicity capability of healthy tissues adjacent the target tumor volume may limit some high-dose therapy, which is a source of worry.

As a case study, 2DXRT planning for radiation treatment of the prostate gland may not have been able to achieve tumor control because of the sensitivity of the nearby rectum to doses. Before the development of CT, physicians and physicists were unable to accurately measure the amount of radiation absorbed by malignant and healthy tissue. As a basis, 3-D conformal radiation therapy has become the standard of care for almost all tumor types and sites. MRI, PET, SPECT, and Ultrasound have also been employed in recent years.

Stereotactic radiation

External beam radiation therapy with a customized beam is known as stereotactic radiotherapy. Using incredibly precise imaging scans, it directs concentrated radiation beams at a well-delineated tumor. Oncologists use stereotactic therapy to treat cancers of the brain and spine, frequently with the assistance of a neurosurgeon.

Stereotactic radiation can be divided into two categories: infrared and ultraviolet. Stereotactic radiosurgery is defined as the application of single or many stereotactic radiation treatments to the brain or spine (SRS). SBRT is a type of stereotactic radiation therapy in which the body is used as a treatment target.

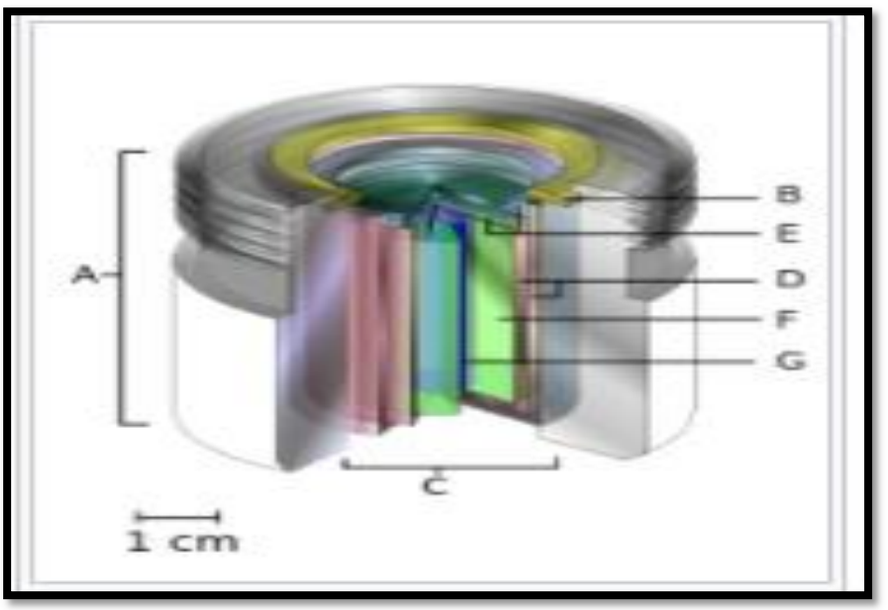
Stereotactic therapies, according to some experts, have the advantage of delivering the optimum quantity of radiation to cancer in a shorter amount of time than normal treatments. On average, it takes 6 to 11 weeks to complete. In addition, treatments are administered with high precision, This should reduce the amount of radiation that reaches healthy tissues and organs. There is a drawback to stereotactic therapies in that they are only effective for specific types of tiny cancers.

Because many institutions refer to stereotactic treatments by their manufacturer's name rather than SRS or SBRT, stereotactic treatments might be confusing. These therapies are marketed under the names (Axesse, Cyberknife, Gamma Knife, Novalis, Primatom, Synergy, X-Knife, TomoTherapy, Trilogy, and Truebeam). As equipment manufacturers develop new, specialized technologies to treat cancer, this list will continue to increase.

Three-dimensional conformal radiation treatment and virtual simulation

Three-dimensional CT / MRI scanners and planning software have changed treatment planning for radiotherapy by making it possible to identify tumors and their surrounding healthy tissue in three dimensions. It is difficult to accurately place radiation beams using standard X-rays on soft tissue structures, As a result, the most basic planning tool, virtual simulation, enables for more exact radiation beam placement. Virtual simulation can be improved by using 3-dimensional conformal radiation therapy (3DCRT), which uses a multileaf collimator and a variable number of beams to modify the profile of each radiation beam to match that of the target from the beam's point of view (BEV). When the treatment volume conforms to the shape of the tumor, the relative toxicity of radiation to surrounding normal tissues is

minimized, allowing a larger radiation dose to be given to the tumor than would be achievable with standard techniques.



The following are the components of a teletherapy radiation capsule:

1) a holder of a global standard source (usually lead),

2) a retaining ring, and

3) a teletherapy "source" composed of

4) two nested stainless steel canisters welded to

5) two stainless steel lids surrounding

6) an internal protective shield (usually uranium metal or a tungsten alloy)

7) a cylinder containing radioactive source material, usually cobalt-60 but not always. The "source" has a diameter of 30 mm.

Intensity-modulated radiation therapy (IMRT)

IMRT, the next generation of high-precision radiation after 3DCRT, is an enhanced form of intensity-modulated radiation therapy. IMRT can better handle a concave tumor form, such as when it wraps around a delicate structure like the spinal cord, an organ, or a blood supply. An x-ray accelerator is a piece of medical equipment that

delivers precise doses of radiation to malignant tumors or specific spots inside tumors using computer control. To calculate the radiation delivery pattern, optimization and treatment simulations are carried out using specialist computer tools (Treatment Planning). The radiation beam's intensity can be adjusted to match the tumor's 3-D shape. The intensity of the radiation dose close the tumor volume is increased, while radiation doses in the surrounding normal tissues are minimized or avoided entirely. As a result, there are fewer side effects, better tumor targeting, and better treatment outcomes.

Although 3DCRT is still frequently used in many body sites, IMRT is growing more common in more complex body locations such as the CNS, head and neck, prostate, breast, and lung. Unfortunately, IMRT's application is limited due to the additional time it demands from competent medical practitioners. This is because clinicians must manually delineate tumors on each CT scan, which takes significantly longer than 3DCRT preparation. In order to design a practical treatment approach, medical physicists and dosimetrists must be involved. Furthermore, even at the most advanced cancer centers, IMRT technology has only been commercially available since the late 1990s, thus radiation oncologists who did not learn it as part of their residency programs must seek additional education before using it.

It's becoming more and more clear that either of these two approaches can help patients live longer than traditional radiation therapy (2DXRT). Prof Christopher Nutting of the Royal Marsden Hospital has been a leading influence behind several significant head and neck cancer investigations. Both methods allow for a gradual increase in dose, which increases their potential use. There has been considerable worry regarding the increased exposure of typical tissue to radiation and the risk for secondary cancer with IMRT. There's a chance that lesions that aren't visible on planning scans (as a result of which they are not involved in the treatment plan) or that migrate during therapy, for example, due to respiration or poor patient immobilization, will go unnoticed. Real-time imaging and real-time therapy beam adjustment are two novel ways being investigated to better control this uncertainty. This cutting-edge method is referred to as image-guided radiation treatment (IGRT) or four-dimensional radiation therapy. Another approach is to use small implantable electric devices to track and locate the tumor in real time. Various medical implanted devices are utilized for this purpose. It might be a magnetic transponder that detects the magnetic field generated by many transmitting coils and provides the readings to the positioning system to establish its location. [63] The implantable device can also

be a small wireless transmitter that sends out an RF signal, which is subsequently received by a sensor array and used for tumor location and real-time tracking.

IMRT has the " Effect of tongue and groove " which causes underdosing due to the irradiation of lengthy tongues and grooves of overlapping MLC (multileaf collimator) leaves. While there have been remedies developed to this problem that either lessen or eliminate the TG impact, they are dependent on the IMRT technology utilized, and some of them come with their own expenses. Depending on whether both or one side of the aperture is obstructed, some literature differentiates between " tongue and groove error" and " Error with dialect and groove."

Volumetric modulated arc therapy (VMAT)

VMAT (volumetric modulated arc treatment) is a radiation technology that can produce extremely conformal dose distributions on target volume coverage while preserving healthy tissues. It originally appeared in 2007. While using this technique, three parameters can be adjusted during the procedure. The medical linear accelerator's MLC (sliding window mechanism of movement) and fluence output rate (dose rate) are used to change the beam's speed and shape, which is delivered by a rotating gantry (usually 360° rotating fields with one or more arcs). When comparing static field intensity modulated radiation to standard static field intensity modulated radiation, this method is more effective (IMRT), VMAT provides the advantage of faster radiation delivery to the patient. Depending on the type of malignancy, When it comes to protecting healthy tissues and organs at risk, VMAT and standard IMRT can be contrasted (OAR). In the treatment of nasopharyngeal, oropharyngeal, and hypopharyngeal carcinomas, VMAT gives equal or better OAR protection than other treatments. VMAT. Currently, the evidence for VMAT or IMRT in the treatment of prostate cancer is mixed.

TrueBeam Linear Accelerator for IMRT by Varian

Automated planning

The use of computer-aided treatment planning (CATP) is becoming commonplace in radiation oncology. Automated planning can be done in two ways. If the system has access to high-quality plans, he can forecast the target and OAR DVHs from these plans. 1) Knowledge-based planning Protocol-based planning, on the other hand, is a treatment planning system that mimics an experienced treatment planner and iteratively values the protocol's requirements determine the plan's quality. Therapy using particles. An example of a particle therapy is proton therapy, which uses energetic ionizing particles (such as protons or carbon ions) to treat a tumor. The Bragg peak occurs at the particle's range limit, after which the dosage drops to (almost) zero. Using this energy deposition profile, the healthy tissue around the target location receives less energy.

Auger therapy

At the molecular level, Auger therapy (AT) uses a high dosage of ionizing radiation to change molecules on an atomic level. AT does not employ radioactive nuclei to harm cells at the cellular level, it also doesn't use a series of exterior pencil-beams pointing in different directions to zero in on the desired area and provide a dose to the targeted area with a lower dose outside the defined tissue/organ locations. When a

large dose of AT is delivered intracellularly, the goal is to cause molecular damage and reorganization, such as stacking structures, as well as metabolic changes in the cells that are connected to the molecular structures.

Motion compensation

Motion can reduce therapy delivery in numerous types of external beam radiation by pushing target tissue out of, or other healthy tissue into, the intended beam path. Although some form of immobilization is used throughout therapy to avoid large bodily movements, it does not eliminate all motion, such as that caused by breathing. To account for such shifts, several solutions have been proposed. Deep inspiration breath-hold (DIBH) is commonly used for breast treatments when irradiation of the heart is a concern. The patient holds their breath after inhaling to provide a secure position for the therapy beam to be turned on in DIBH. External monitoring equipment, such as a spirometer or a camera and markers, can be used to perform this automatically. The patient breathes normally, but the beam is only activated at certain periods during the breathing cycle, which is known as respiratory gated treatment. can use the same monitoring techniques as well as 4DCT imaging. Other ways include scheduling treatments with motion margins using 4DCT imaging and actively adjusting the treatment sofa, or beam, to track motion.

Contact x-ray brachytherapy

Contact x-ray brachytherapy, often known as "CXB," "electronic brachytherapy," or the "Papillon Technique," is a technique for treating rectal cancer that involves the use of kilovoltage X-rays supplied near the tumor. Large doses of X-rays are emitted directly into the tumor at two-week intervals after introducing the x-ray tube through the anus into the rectum and positioning it against the malignant tissue. It's usually used to treat patients with early rectal cancer who aren't surgical candidates. The most common side effects, according to a 2015 NICE study, were bleeding (38 percent) and radiation-induced ulcers (27 percent).

Brachytherapy (sealed source radiotherapy)

Brachytherapy is administered by inserting a radiation source (or several) inside or near the area to be treated. Brachytherapy is a treatment that is often used to treat cancers of the cervix, prostate, breast, and skin, as well as tumors in other parts of the body.

Brachytherapy is the process of accurately implanting radiation sources at the malignant tumor's location. As a result, irradiation only affects a narrow region, and healthy tissues located further away from the sources are exposed to less radiation. The ability to treat the tumor with exceptionally high doses of focused radiation while reducing the danger of inadvertent injury to neighboring healthy tissues is one of the advantages of brachytherapy over external beam radiation therapy. Brachytherapy is a type of radiation therapy that takes less time to complete than other types of radiation therapy. This may help to reduce the likelihood of cancer cells surviving radiation therapy, dividing and replicating.

The SAVI device, for example, administers the radiation dose via numerous catheters, each of which may be independently adjusted, demonstrating the localized character of breast brachytherapy. This technology decreases the exposure of healthy tissue and the associated side effects when compared to both external beam radiation therapy and older methods of breast brachytherapy.

A SAVI brachytherapy device

Adionuclide therapy

A type of targeted therapy, radionuclide therapy (also known as systemic radioisotope therapy, radiopharmaceutical therapy, or molecular radiotherapy) is a type of radionuclide therapy. The chemical properties of isotopes like radioiodine, which is absorbed 1,000 times better by the thyroid gland than by other human organs, allow for precise targeting. Binding the radioisotope to another molecule or antibody can also help it find its way to the right spot. The two techniques of administering radioisotopes are infusion (into the bloodstream) or ingestion. MIBG infusions for neuroblastoma, oral iodine-131 for thyroid cancer or thyrotoxicosis, and hormone-bound lutetium-177 and yttrium-90 for neuroendocrine tumors are only a few of the treatments available (peptide receptor radionuclide therapy). The injection of radioactive yttrium-90 or holmium-166 microspheres into the hepatic artery is another example of radioembolization of liver tumors or metastases. Selected internal radiation treatment is a therapeutic method that uses these microspheres. The microspheres, which have a diameter of about 30 m, or one-third the width of a human hair, are injected directly into the tumor-supplying artery. These procedures begin with the insertion of a catheter into the femoral artery in the leg, which is subsequently guided to the target area and treated. The microspheres will be carried straight to the tumor by the blood that feeds it, allowing for a more targeted treatment than traditional systemic chemotherapy. SIR-Spheres, Thera Spheres, and Quirem Spheres are the three varieties of microspheres now available.

The treatment of cancer-related bone metastases is one of the most common applications of systemic radioisotope therapy. The radioisotopes move to areas of injured bone only, leaving normal, healthy bone alone. The isotopes radium-223, strontium-89, and samarium (153Sm) lexidronam are routinely used in the treatment of bone metastases.

The United States Food and Drug Administration (FDA) approved ibritumomab tiuxetan (Zevalin) in 2002, which is an anti-CD20 monoclonal antibody conjugated to yttrium-90. The FDA approved the tositumomab/iodine (131I) tositumomab regimen (Bexxar) in 2003, and it consists of an anti-CD20 monoclonal antibody that has been tagged with iodine-131 and an unlabeled anti-CD20 monoclonal antibody. [97] These were the first drugs to be approved for the treatment of refractory non-lymphoma, Hodgkin's Hodgkin's disease, and radioimmunotherapy.

Intraoperative radiotherapy

Intraoperative radiation therapy (IORT) is the process of applying therapeutic doses of radiation to a specific area during surgery, such as a malignant tumor.

Rationale

The goal of IORT is to provide a high dose of radiation to a single target while minimizing radiation exposure to nearby tissues that are relocated or protected. Traditional radiation techniques, such as external beam radiotherapy (EBRT), have substantial drawbacks after surgical resection of the tumor: Even though current radiation planning is carried out, owing to the complicated localization of the wound cavity, the tumor bed where the maximum dosage should be supplied is frequently neglected. Furthermore, the time between surgical tumor excision and EBRT may allow tumor cells to repopulate. These potentially dangerous side effects can remain prevented by carefully delivering radiation to the targeted organs, resulting in quick sterilization of any remaining tumor cells. The fact that wound fluid stimulates tumor cells is another factor to consider. The stimulant effects of wound fluid were found to be inhibited by IORT.

Radiotherapy

One of the most commonly used cancer treatments is chemotherapy. It entails the use of various types of radiation (Particles, X-rays, and Gamma rays) to injure and eliminate tumors, either alone or in conjunction with surgery or chemotherapy. External (teletherapy) or internal (radiotherapy) radiotherapy are two different types of radiotherapy (brachytherapy).

Teletherapy

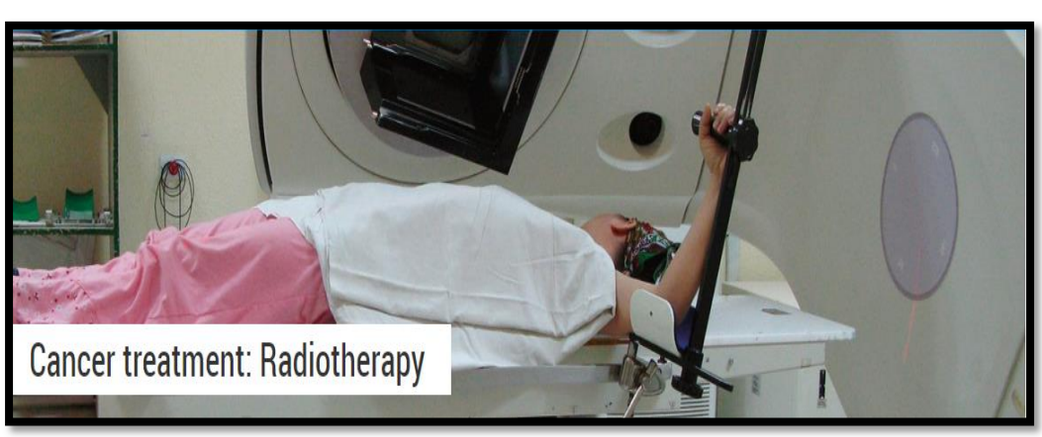
Teletherapy is the use of an external radiation source to deliver radiation therapy to the body from a distance. It is the most common type of cancer treatment, and it is frequently administered using a Cobalt unit, which emits high-energy gamma rays, or a linear accelerator, which emits high-energy X-rays or electrons. Treatment is usually given once a day for 4 to 8 weeks in the most popular regimen.

The radiation source is placed at a distance from the patient to ensure a uniform dose of radiation is delivered to the target, which can be several centimeters thick (usually 80-150 cm). In the path of the beam, healthy tissue, including skin, can be irradiated as well. Higher-energy beams are employed for deeper tumors to lessen this impact, and treatment is provided from multiple angles to optimize the dose at the intersection.

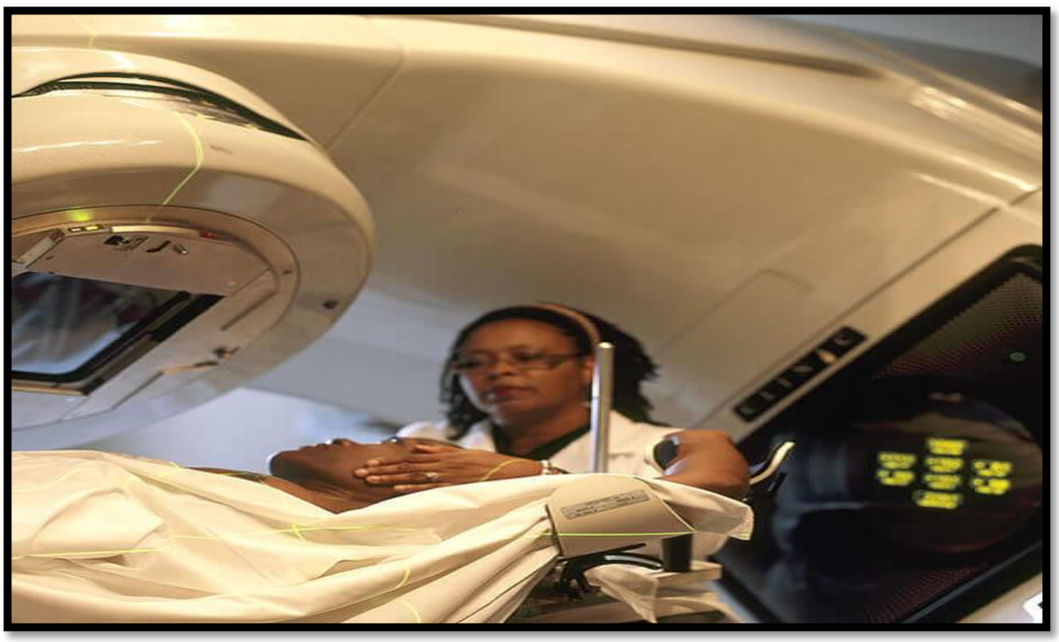
Modern teletherapy techniques

Modern radiotherapy techniques, such as 3-D conformal radiotherapy, intensity modulated radiotherapy, and image guided radiotherapy, achieve an extremely precise sculpting of the target that receives the specified dose of radiation. These techniques allow radiotherapy to deliver a lesser dose to healthy tissues while increasing the dose on the tumor. Patients undergoing radiotherapy experience no bodily feelings while being subjected to radiation; it's akin to having an X-ray. There are, however, drawbacks. Early reactions in rapidly dividing tissues like mucosa and skin resemble 'sunburn.' Tolerance to radiation is lower in slow dividing cells, such as those in the kidney or the vasculature supporting the brain and spinal cord. They are at risk of developing late effects if they are treated above a certain threshold. These effects usually appear months after treatment.

The use of modern technologies allows for significant spatial sparing of important organs. Another useful technique is radiobiological research, which aids in the selection of the best treatment options. There should be a thorough quality assurance program in place.



Cancer Treatment Using Radiation



Radiation therapy (also known as radiotherapy) is a cancer treatment that involves giving cancer cells high doses of radiation to kill them and shrink tumors. X-rays, such as those of your teeth or damaged bones, use radiation to examine inside your body at low levels.

How does radiation therapy work cancer?

Radiation therapy destroys cancer cells or limits their growth by destroying their DNA at high doses. Cancer cells that have had their DNA damaged beyond repair either cease proliferating or die. The body breaks down and removes damaged cells when they die. Cancer cells are not killed immediately by radiation therapy. It can take days or weeks for cancer cells to die due to DNA damage. After radiation therapy is finished, For weeks or months, cancer cells are still dying.

Types of radiation therapy

External beam and internal radiation therapy are the two primary types of radiation therapy.

Many factors influence the type of radiation therapy you receive, including:

• The cancer's type

• The tumor's size

• The tumor's location in the body.

• How near the tumor is to radiation-sensitive normal tissues.

• Your overall health and medical background.

• Whether you'll need additional cancer treatments.

• Other considerations, such as your age and any existing medical issues

External beam radiation therapy

A machine directs radiation at your cancer in external beam radiation therapy. The machine is massive and obnoxiously noisy. It doesn't touch you, but it can move about you, sending radiation in all directions to a certain part of your body.

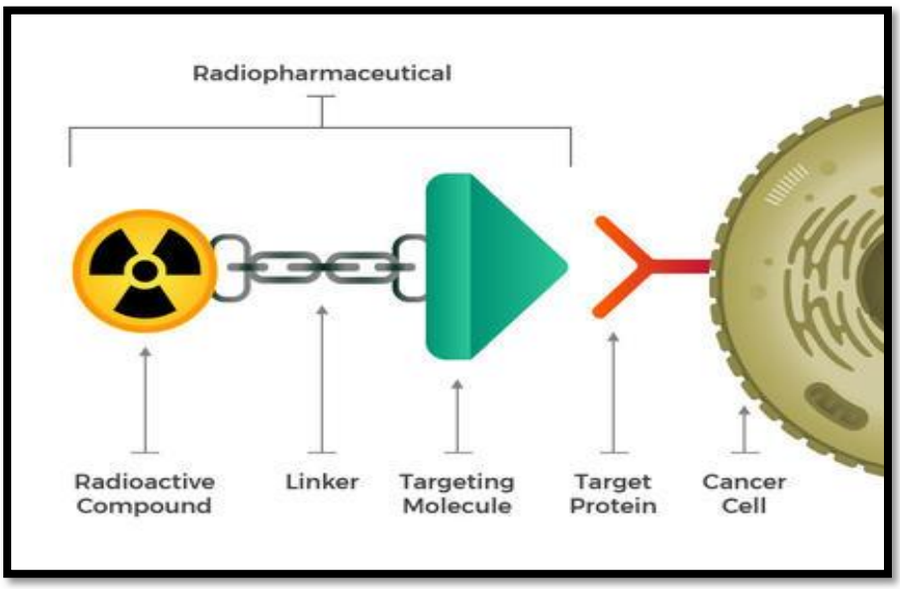
External beam radiation therapy is a local treatment, meaning it only affects one portion of your body. For example, if you have lung cancer, you will just receive radiation to your chest, not your entire body.

Internal radiation therapy

Internal radiation therapy is a treatment in which a radiation source is implanted into your body. Radiation can be produced by either a solid or a liquid source. Internal radiation therapy with a solid source is referred to as brachytherapy. This method of treatment involves implanting seeds, ribbons, or capsules with a radiation source in or around the tumor. Brachytherapy, like external beam radiation therapy, is a localized treatment that affects only a small part of your body. During brachytherapy, the source of radiation in your body emits radiation for a brief time.

Learn more about brachytherapy.

Systemic therapy is a type of internal radiation therapy that uses a liquid source. The phrase "systemic" refers to a treatment that spreads throughout your body via your bloodstream, looking for and eradicating cancer cells. You can get systemic radiation therapy by ingesting it, injecting it, or getting it through a vein via an IV line. For a period of time, systemic radiation causes your liquids, such as urine, perspiration, and saliva, to create radiation.



New Cancer Therapies Based on Radiation

Radiation therapy is delivered directly and specifically to cancer cells using radiopharmaceuticals.

Why people with cancer receive radiation therapy

Radiation therapy is a cancer treatment that is used to both cure and treat the symptoms of cancer. Radiation therapy can cure cancer, prevent it from recurring, and reduce or stop its progression when used to treat it.

Palliative care refers to treatments that assist patients cope with their symptoms. Pain and other symptoms induced by malignancies, such as difficulty breathing and bowel and bladder control loss, can be treated using external beam radiation. Radiopharmaceuticals, or systemic radiation treatment drugs, can be used to alleviate pain caused by cancer that has spread to the bones.

Types of cancer that are treated with radiation therapy

Many forms of cancer are treated using external beam radiation treatment.

Head and neck cancers, breast cancer, cervical cancer, prostate cancer, and eye cancers are the most common cancers treated with brachytherapy. Thyroid cancer is most commonly treated with a systemic radiation therapy named radioactive iodine, or I-131. Targeted radionuclide therapy is another sort of systemic radiation therapy

that is used to treat individuals with advanced prostate cancer or gastroenteropancreatic neuroendocrine tumors (GEP-NET). Molecular radiotherapy is another term for this sort of treatment.

How is radiation used with other cancer treatments?

Radiation therapy may be the only option for some patients. But, radiation therapy is frequently combined with other cancer treatments such surgery, chemotherapy, and immunotherapy. To boost the chances of therapeutic success, radiation therapy may be used before, during, or after these other therapies. The length of radiation therapy depends on the type of cancer being treated and if the goal of the treatment is to cure the disease or relieve symptoms.

When radiation is combined with surgery, it can be given:

Before surgery, to shrink the size of the cancer so it can be removed by surgery and be less likely to return.

• During surgery, so that it reaches the malignancy directly rather than going through the skin. Intraoperative radiation is the term for this type of radiation therapy. Doctors can more readily safeguard neighboring normal tissues from radiation with this technique.

• Kill any cancer cells that remain after surgery.

Lifetime dose limits

Over the course of your lifetime, The amount of radiation that a part of your body can safely receive has a limit. Depending on how much radiation has already been delivered to that area, you may not be able to undergo radiation therapy to that same site a second time. However, if one part of the body has already received the safe lifetime dosage of radiation, another part of the body may still be treated if the distance between the two is big enough.

Radiation therapy can cause side effects

Radiation can destroy or slow the growth of cancer cells while also harming nearby healthy cells. When healthy cells are destroyed, side consequences could arise.

How much radiation therapy costs?

Radiation therapy is not cheap. It makes use of sophisticated machines and enlists the help of numerous health-care professionals. The cost of your radiation therapy is determined by the cost of health care in your area, the type of radiation therapy you receive, and the number of treatments you require. Discuss what services your health insurance will cover with your provider. Most insurance coverage cover radiation therapy. For more information, contact the business office of the clinic or hospital where you are having treatment. If you require financial assistance, there are organizations that may be able to assist you. To find such groups, look up "financial aid" in the National Cancer Institute's Groups that Offer Support Services database. Call 1-800-4-CANCER (1-800-422-6237) for information on support groups that may be able to help you.

Special diet needs while on radiation therapy

Radiation can produce nausea, mouth sores, and esophagitis, which make it difficult to eat. Radiation therapy causes your body to expend a lot of energy in order to heal. it's critical that you eat enough calories and protein to stay in shape.

Talk to your doctor or nurse if you're having difficulties eating and maintaining your weight. Speaking with a dietitian might also be beneficial. See the booklet Eating Hints for further information on managing with eating disorders, or learn more about side effects.

Working during radiation therapy

About half of patients can work full-time throughout radiation therapy. Others might only be able to work part-time or not at all. Depending on how you feel, you can work as much as you like. Inquire with your doctor or nurse about the treatment options available to you. When you initially start your radiation treatments, you may

feel healthy enough to work. If you get fatigued, don't be surprised. lose energy, or feel weak over time. It could take a few weeks or months after you finish treatment to feel better. You may become too unwell to work at some point throughout your radiation therapy. Check with your boss to see if you're eligible for medical leave. Check with your health insurance to see if treatment will be covered while you're on medical leave.

Cancer continues to be the greatest cause of mortality worldwide. According to the International Agency for Research on Cancer (IARC), cancer causes 7.6 million deaths worldwide each year, with 12.7 million new cases reported each year. Developing countries bear a substantial amount of this burden; developing countries account for 63 % of cancer fatalities [1, 2, 3]. Cancer is a multigenic and multicellular disease that has a multifactorial origin and can attack any cell type or organ. Six cancer cell phenotypes or hallmarks were identified by Hanahan and Weinberg 4: cells with unconstrained proliferative capabilities, environmental independence for proliferation, apoptosis evasion, angiogenesis, invasion, and metastasis to diverse parts of the body.

If uncontrolled cell growth or metastatic metastasis happens, the person will die. [5]. Over the last decade, significant progress has been made in the treatment and understanding of the previously proposed cancer hallmarks. Many malignancies have become treatable as a result of breakthroughs in early identification and treatment approaches [6].

The scientific relevance of X-rays as a cancer treatment was first realized when Wilhelm Conrad Röntgen from Germany discovered them in 1895. Marie Curie received her second Nobel Prize for her work on radium one hundred years ago, cementing her reputation as a pioneer in the field of radiation therapy. The United Kingdom has designated 2011 as the Year of Radiation Therapy to recognize a century of progress. Since then, radiation therapy has developed into a recognized medical specialty, with Radiation Oncology serving as a discipline that brings together health and scientific experts from several fields. In addition to surgery and chemo, radiation therapy, often known as radiotherapy, is a very cost-effective single modality treatment that accounts for just around 5% of the entire cost of cancer care. 8. Furthermore, around half of all cancer patients will undergo radiation therapy at some point throughout their illness [9, 10], with radiation therapy accounting for roughly 40% of all curative treatments 11. Advances in imaging techniques, computerized treatment planning systems, radiation treatment machines (with improved X-ray

production and treatment delivery), and a better understanding of the radiobiology of radiation therapy [12] are all helping to propel rapid advancement in this sector.

Principles of Radiation Therapy

Radiation is a type of physical agent used to kill cancer cells. Because it generates ions (electrically charged particles) and deposits energy in the cells of the tissues it passes through, the radiation employed is known as ionizing radiation. This stored energy has the potential to destroy cancer cells or create genetic alterations that lead to cell death.

High-energy radiation damages cells' genetic material (deoxyribonucleic acid, or DNA), preventing them from dividing and proliferating further 13. Despite the fact that radiation destroys both normal and cancer cells, the purpose of radiation treatment is to increase the radiation dose to aberrant cancer cells while reducing exposure to normal cells adjacent to cancer cells or in the path of radiation. Normal cells, on the other hand, can usually repair themselves faster and maintain their normal function status than cancer cells. Cancer cells in general are less effective than normal cells at repairing radiation-induced damage, resulting in differential cancer cell death [10].

Radiation can be used as a curative treatment or as a palliative treatment to reduce cancer-related symptoms. Combination methods with other treatment techniques including surgery, chemotherapy, or immunotherapy are also examples of radiation therapy indications. Radiation can reduce a tumor if it is given before surgery (neoadjuvant therapy). Radiation, when administered after surgery (adjuvant therapy), will eliminate any remaining tiny tumor cells. The vulnerability of malignancies to radiation treatment is widely established.

Table 1

Examples of cancers treated with radiation therapy.

Early cancers curable with radiation therapy alone	Cancers curable with radiation therapy in combination with other modalities
Skin cancers (Squamous and Basel cell)	Breast carcinomas
Prostate carcinomas	Rectal and anal carcinomas
Lung carcinomas (non-small cell)	Local advanced cervix carcinomas
Cervix carcinomas	Locally advanced head and neck carcinomas
Lymphomas (Hodgkin's and low grade Non-Hodgkin's)	Locally advanced lung carcinomas
Head and neck carcinomas	Advanced lymphomas
	Bladder carcinomas
	Endometrial carcinomas
	CNS tumors
	Soft tissue sarcomas
	Pediatric tumors

There are two methods for delivering radiation to the cancer's site. External beam radiation is supplied from the outside of the body by directing high-energy rays (photons, protons, or particle radiation) at the tumor. In the clinical setting, this is the most common strategy. Internal radiation, also known as brachytherapy, is given to the tumor site from within the body using radioactive sources sealed in catheters or seeds. Because of its short-term effects, it is commonly employed in the normal treatment of gynecological and prostate cancers, as well as in circumstances where retreatment is required.

Radiation Therapy Techniques

Fractionation

The different radiobiological characteristics of cancer and other normal tissues are used to administer fractionated radiation therapy. In general, these regimes augment normal tissues' survival advantage over cancer cells, owing to greater sublethal radiation damage repair in normal cells vs malignant cells Normal cells replicate at a slower rate than cancer cells, allowing them to fix damage before to duplication The effects of fractionated radiation therapy were first identified in the 1920s, prompting the development of regimens that compared various treatment schedules based on

total dose, number of fractions, and overall treatment time 14. Current treatments use a more refined linear-quadratic model that takes time-dose factors for various tumor types and normal tissues into account 15. A typical radiation therapy treatment schedule includes daily fractions of 1.5 to 3 Gy spaced out over several weeks.

Technological advances

The goal of radiotherapy is to provide as much radiation to the tumor as feasible while sparing healthy tissue. This has been made possible by technological advancements including new imaging modalities, more powerful computers and software, and unique delivery systems like enhanced linear accelerators.

3D Conformal radiotherapy (3DCRT)

2D radiation therapy based on rectangular fields and conventional X-ray imaging has largely been superseded by 3D radiation therapy based on CT imaging, which enables for precise localization of the tumor and key normal organ structures for optimal beam placement and shielding. The goal is to deliver radiation to the gross tumor volume (GTV), with a clinical target volume (CTV) margin for microscopic tumor expansion and a planned target volume (PTV) margin to account for organ movements and setup variables.

Intensity modulated radiation therapy (IMRT)

IMRT allows the oncologist to provide irregularly shaped radiation doses that conform to the tumor while sparing important organs. IMRT is made possible by inverse planning software and computer-controlled intensity modulation of multiple radiation beams during treatment. In a variety of clinical settings, Linear accelerators with static or dynamic multi-leaf collimators, as well as tomotherapy equipment, can currently be used to give IMRT. This has improved the therapeutic ratio for a variety of tumor types, such as head and neck malignancies, prostate cancer and gynecological cancers.

Image-guided radiotherapy (IGRT)

As treatment margins get tighter and more conformal, the risk of missing tumor due to organ movements and patient setup changes increases. Even slight placement errors can result in unintended radiation of normal organs when vital tissues are near to the tumor. Using data from pre-radiotherapy imaging, IGRT allows for the discovery and correction of such mistakes. This includes daily cone-beam CT pictures collected before to each treatment. Due to improved accuracy, dose escalation has become achievable, resulting in an improvement in the therapeutic ratio for a variety of tumor types, including head and neck cancers [23] and prostate cancers.

Stereotactic body radiation therapy (SBRT)

SBRT, which precisely delivers very high individual doses of radiation over only a few treatment fractions to ablate tiny, well-defined primary and oligometastatic tumors everywhere in the body, has been enabled by the foregoing technological improvements. Any tissue immediately close to the tumor is likely to be destroyed due to the high radiation exposure. Clinically meaningful toxicity is negligible in the high dosage range because the proportion of normal tissue is tiny and non-eloquent. SBRT has proved to be effective in treating early stage non-small cell lung cancer in patients who are unable to undergo surgery. Others include prostate, head and neck, hepatic, renal, oligometastases, spinal, and pancreatic tumors.

Types of radiation used to treat cancer: photons radiation (x-rays and gamma rays), which are widely used

Photon beams have a very low mass and a very low radiation charge. In the therapy of cancer, photons such as X-rays and gamma rays are routinely used. X-rays and gamma rays are low-LET (linear energy transfer) sparsely ionizing radiations made up of massless energy particles called photons. Devices that stimulate electrons (such as cathode ray tubes and linear accelerators) produce X-rays, while radioactive decay produces gamma rays (e.g.cobalt-60, radium and cesium).

Particle radiations (electron, proton and neutron beams)

Because electron beams do not penetrate deeply into tissues, they are particularly useful for treating tumors on the surface of the body. Heavier particles, such as neutrons produced by neutron generators and cyclotrons, protons produced by cyclotrons and synchrotrons, and heavy ions (helium, carbon, nitrogen, argon, and neon) produced by synchrocyclotrons and synchrotrons, are used in external beam radiation therapy. Proton beams are a type of particle beam radiation that has only lately been employed in cancer treatment. It can give superior dose distribution due to its unique tissue absorption profile, known as the Bragg's peak, which allows maximum destructive energy to be deposited at the tumor site while minimizing damage to healthy tissues along the path. These are particularly useful in pediatric cancers and in adults with tumors near vital systems like as the spinal cord or the skull base, where the preservation of as much normal tissue as possible is essential [31]. After proton beams are diverted to a target, neutrons are created inside neutron generators. They have a higher LET than photons and can damage DNA more. The difficulties in producing neutron particles, as well as the building of such treatment facilities, have been the key factors in the limits.

With a higher biological efficacy, The LET of particle radiation is higher than that of photons. As a result, certain types of radiations may be more effective against malignancies that are radioresistant, Sarcomas, renal cell carcinomas, and melanomas are only a few examples. and glioblastoma. Particle radiation therapy equipment, on the other hand, is significantly more expensive than photon radiation therapy equipment. Proton beam therapy is projected to become more widely used in the future as cyclotron costs fall.

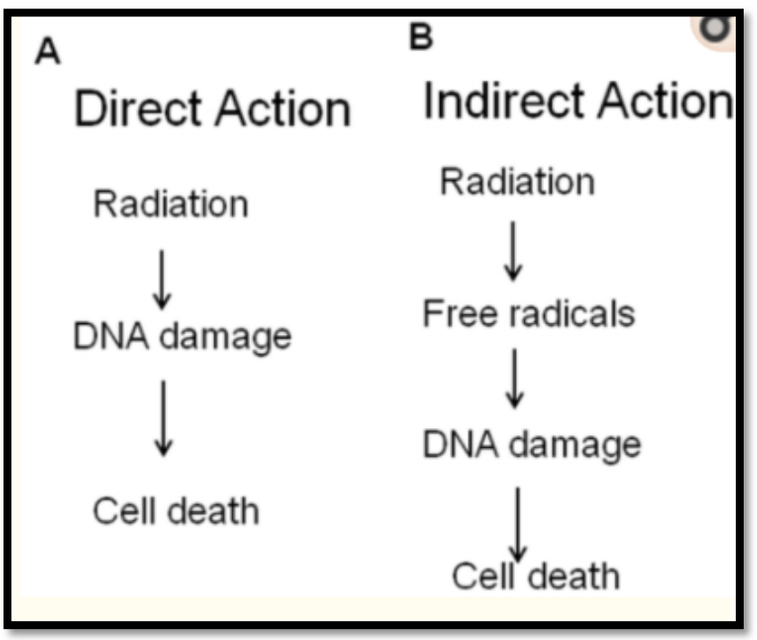
Biological aspects

The biological effectiveness (cell death) of radiation 34, 35 is influenced by the linear energy transfer (LET), total dose, fractionation rate, and radio-sensitivity of the targeted cells or tissues. Low LET radiation leaves a small quantity of energy on the targeted areas, whereas high LET radiation leaves a bigger amount of energy behind. Radiation is designed to kill tumor cells, however it is inescapable that it may harm non-cancerous normal tissues around the tumor. Radiation therapy, on the other hand, aims to increase tumor cell dosage while minimizing damage to healthy cells.

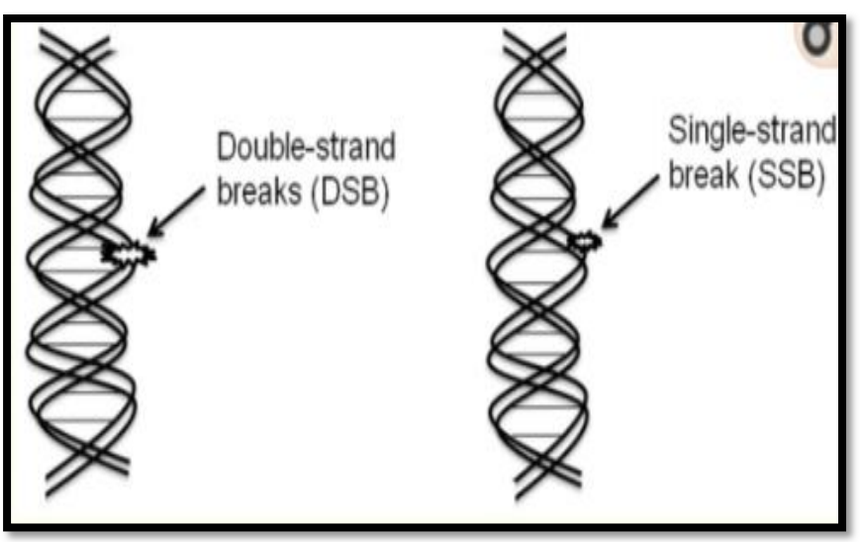
Radiation therapy works through in various ways to remove the cancer cells

The biological target of radiation in the cell is DNA (Figure11).

Direct effects of radiation: Radiation can directly interact with cellular DNA and cause damage (Figure 22A).



2. Radiation's indirect effects: When the water component of cells is ionized or excited, free radicals cause indirect DNA damage.



Double-strand DNA breaks are irreversible, and they are more responsible than single-strand DNA breaks for the majority of cell death in cancer and surrounding normal cells.

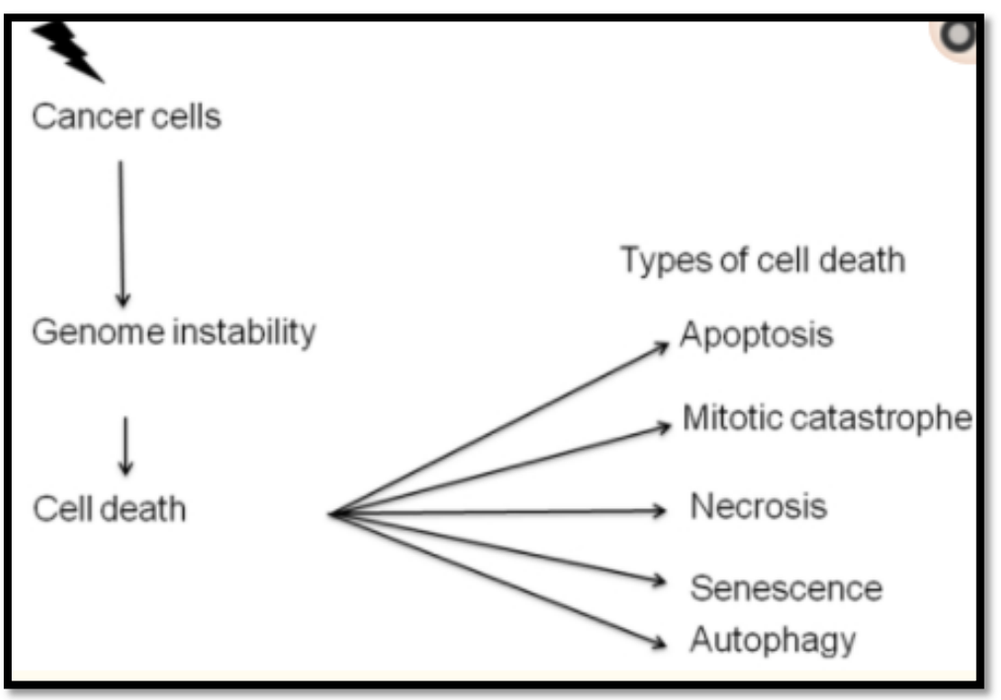
Radiation therapy and cell death

Radiation therapy uses a variety of methods to eliminate cancer cells. The basic goal of radiation therapy is to deprive cancer cells of their ability to proliferate and, as a result, to kill them. Cancer cells that have had their DNA damaged beyond repair cease proliferating and eventually die.

The mechanism of irradiation-induced cell death, on the other hand, is complicated. As a result, determining the significance of radiation-induced cell death and the additional processes involved could have clinical implications for enhancing radiation therapy outcomes.

Types and characteristics of cell death

Radiation therapy, like the majority of anticancer treatments, works by triggering various forms of cell death 37. Radiation therapy does not immediately kill cancer cells. After hours, days, or weeks of treatment, cancer cells begin to die, and they continue to die for weeks to months after radiation therapy has ended.



Apoptosis, or programmed cell death, is a significant cell death mechanism used in cancer therapy, particularly radiation therapy. Cell shrinkage and the development of apoptotic bodies are signs of apoptosis. Mitochondria are essential for apoptotic cell death. Cell membrane blebbing is frequently caused by reduced chromatin, nuclear margination, and DNA fragmentation. The cellular membranes of apoptotic cells are usually undamaged. Radiation therapy's capacity to cause cancer cells to die is critical.

Mitotic cell death or Mitotic catastrophe

This type of cell death is produced by chromosome mis-segregation, which results in the creation of large cells with abnormal nuclear morphology and numerous nuclei during or after aberrant mitosis (cell division). Micronuclei are seen in many cells, and centrosome duplication is common. After irradiation, the majority of solid tumor cell death is caused by abnormal mitotic processes. The majority of ionizing radiation-induced cell death is caused by these two forms of cell death.

Necrosis: When the cell membrane breaks down, the cells enlarge noticeably. The nuclear form of the cells is unusual, Vacuolization, non-condensed chromatin, and fragmented cellular organelles, as well as mitochondrial expansion and plasma membrane rupture, are all associated with intracellular content loss. Necrosis is less common after radiation, but it does happen in cancer cell lines or tissues.

Senescence: Senescence is a condition in which a cell's ability to reproduce is permanently lost. Senescent cells are alive but do not divide; they stop synthesizing DNA, and ultimately die. expand and flatten, and their granularity increases. Senescence has been described in cancer lockups after substantial cellular stress in the form of DNA damage generated by radiation treatment and the cells eventually die mostly through the apoptosis mechanism.

Autophagy: Autophagy is a phenomenon that has only recently been documented. It is a type of radiation-induced cancer cell death. Autophagy is a genetically controlled form of programmed cell death in which the cell digests itself and utilizes the autophagic/lysosomal compartment. The creation of double-membrane vacuoles in the cytoplasm, which trap organelles such as condensed nuclear chromatin and ribosomes is one of its hallmarks.

A range of genetic factor and intracellular pathways are thought to be involved in radiation-induced cell death. The ATM-p53-Bax-Cytochrome c-Caspases route 51 has been associated to apoptosis, while the p53-Caspases-Cytochrome c cascade 52 has been linked to mitotic catastrophe. Necrosis is connected to the TNF (alpha) - PARP-JNK-Caspases route 53, while senescence is linked to the MYC-INK4A-ARF-p53-p21 pathway 54. Autophagy is assumed to be mediated by the PI3K-Akt-mTOR cascade 55. Despite the fact that the majority of these channels are interrelated for radiation-induced cancer cell death, there is still much to learn about the cell death pathways that lead to carcinogenesis and radiation treatment resistance in cancer cells. However, the actual mechanism(s) underlying the multiple forms of cancer cell killing induced by radiation remain unknown. Recent years have seen a rapid growth in our understanding of the several biochemical trackways involved in determining cell death after exposure to radiation. The processes of DNA damage response and repair, intracellular signaling in response to single or fractionated radiation, and radiation's impact on the tumor microenvironment are all of interest. Tumor profiling, thanks to advancements Sequencing a genome should allow for more personalized treatment employing risk stratification methodologies and a more precise molecular targeted anticancer approach of radiation therapy in the coming decade.

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