RADIATION BIOPHYSICS

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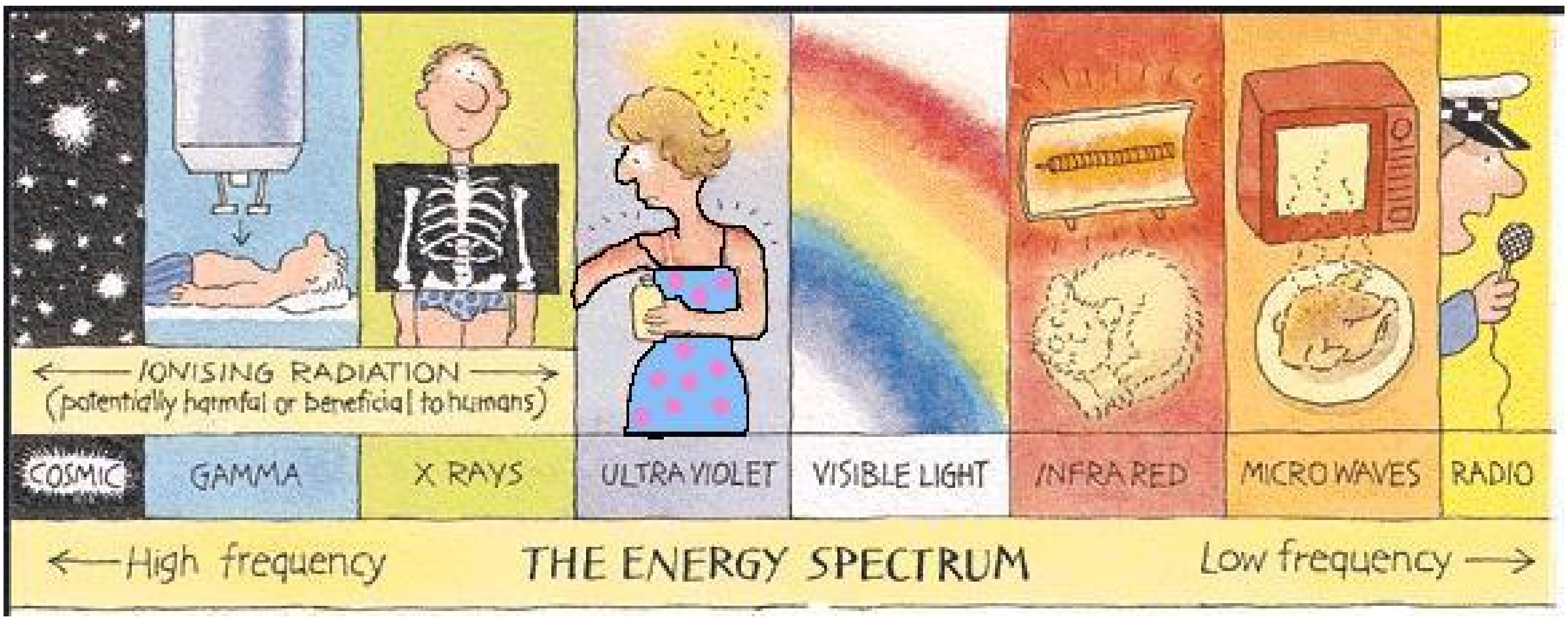
Radiation

- The process of emitting energy in the form of waves or particles



Where does radiation come from?

- Radiation is generally produced when particles interact or decay.
- A large contribution of the radiation on earth is from the sun (solar) or from radioactive isotopes of the elements (terrestrial).

Classification of Radiation

- Energy
  - low-energy radiation (non-ionizing) and
  - high-energy radiation (ionizing)
- Type
  - particle radiation and
  - electromagnetic radiation
- Source
  - natural radiation sources
  - man-made radiation sources

Classification of Radiation
Energy

- **Non-ionizing radiation** (cannot ionize matter)
  - Microwaves, visible light, radio waves, infrared, etc.
- **Ionizing radiation** (can ionize matter)
  - High-frequency radiation that has enough energy ($E > 10eV$ *) to remove an electron from (ionize) an atom or molecule.
  - Gamma rays, x-rays, some high-energy UV rays, and some sub-atomic particles such as alpha particles and protons are forms of ionizing radiation.

Ionization: Process in which an atom or molecule acquires a positive charge (by losing electrons) or negative charge (by gaining electrons).

* ***eV; electronvolt:*** *The amount of energy gained (or lost) by the charge of a single electron moved across an electric potential difference of one volt.* ***1eV= 1,6x10^{-19} Joule***

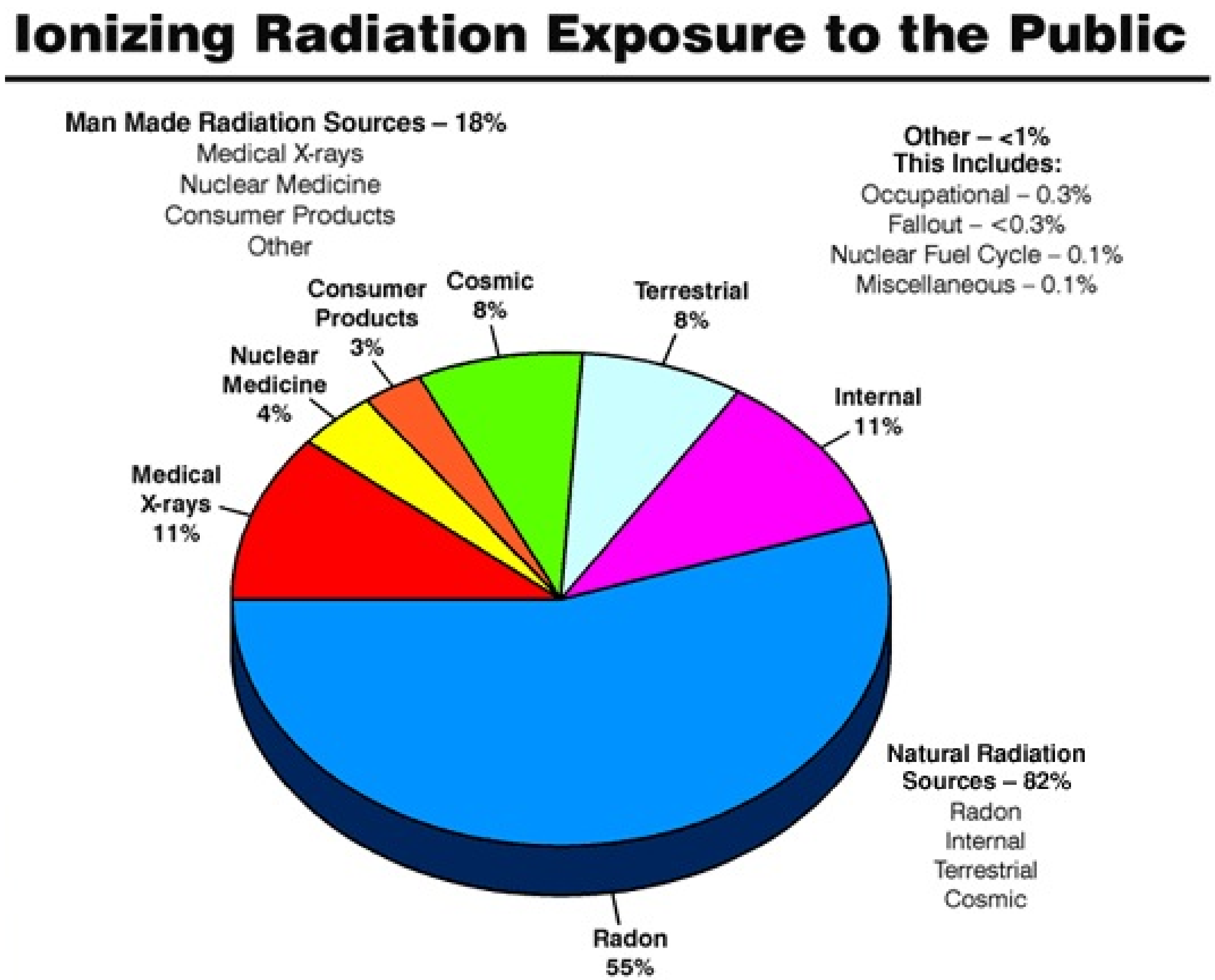
Classification of Radiation
Energy

- Ionizing radiation
  - **Directly ionizing radiation (charged particles)**
    - electron, proton, alpha particle, heavy ion
  - **Indirectly ionizing radiation (neutral particles)**
    - photon (x ray, gamma ray), neutron

Classification of Radiation
Type

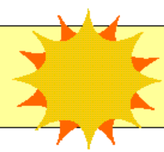
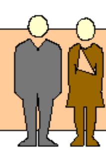
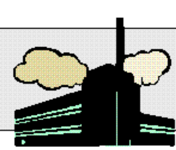
- **Particle Radiation**
  - Alpha
  - Beta
  - Neutron
  - Proton
- **Electromagnetic Radiation**
  - Gamma rays
  - X-Ray
  - Ultraviolet
  - Visible light
  - Infrared
  - Radio waves

Classification of Radiation Source



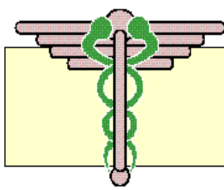
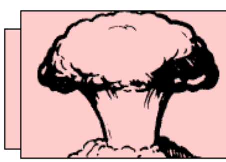
NATURAL RADIATION SOURCES

Radiation from Natural Sources

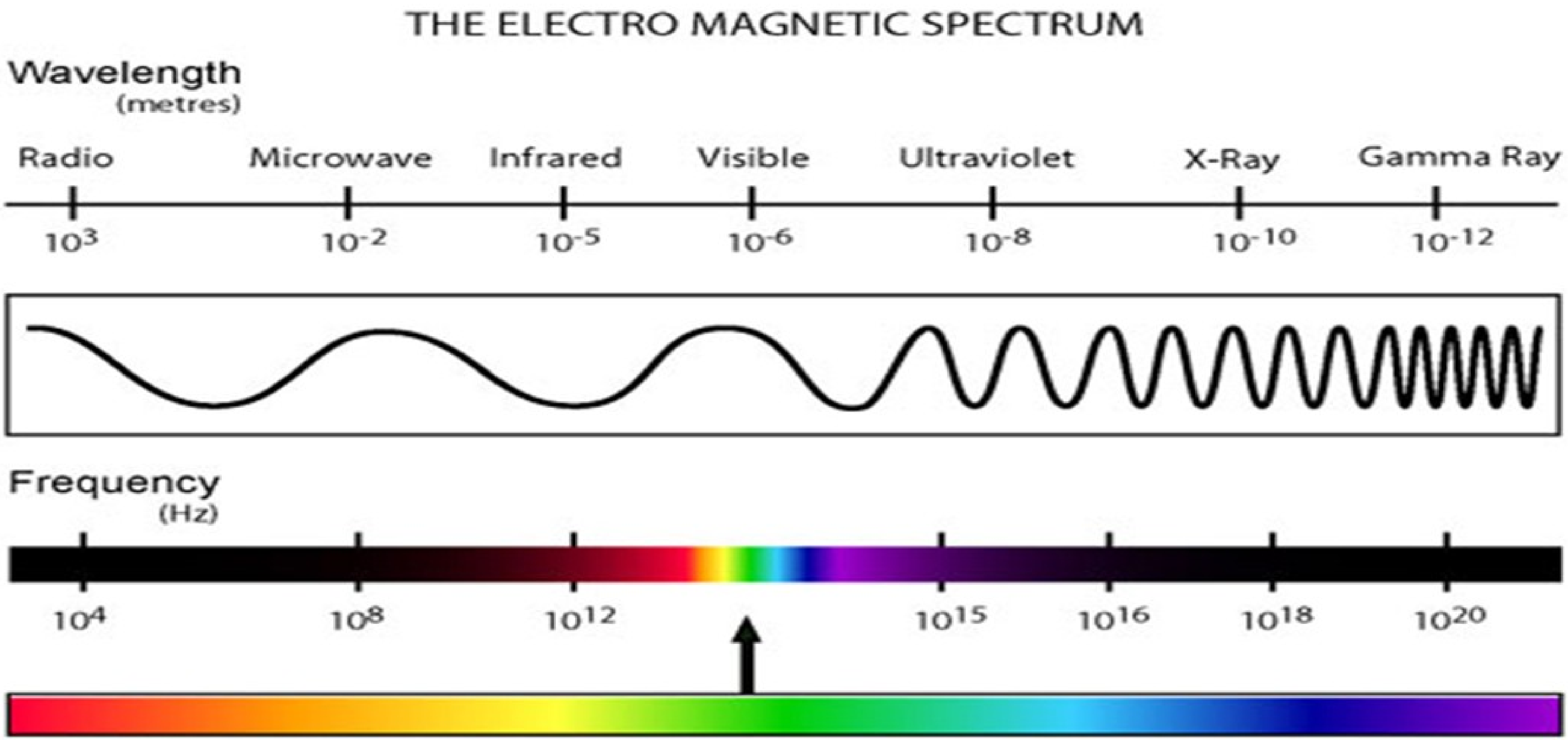
	Source	mrem/year
	Cosmic rays	28
	The earth	26
	Radon	200
	The human body	25
	Building materials	4

MANMADE RADIATION SOURCES

Radiation from Manmade Sources

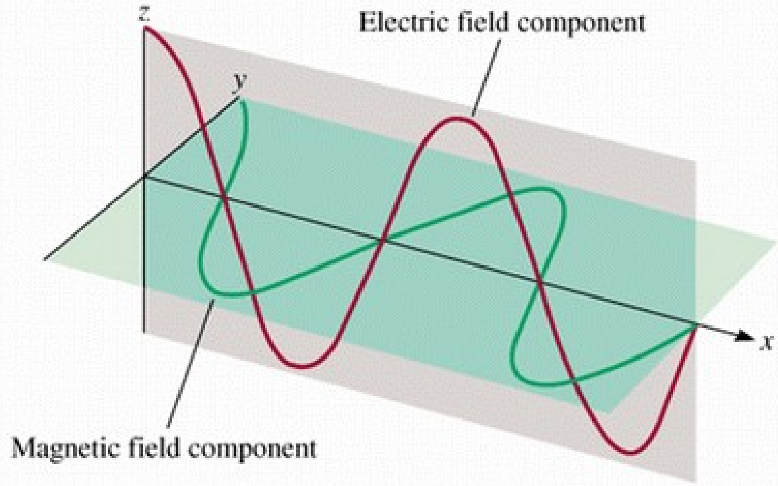
	Source	mrem/year
	Medical	90
	Fallout	5
	Consumer products	1
	Nuclear power	0.3

THE ELECTROMAGNETIC SPECTRUM



Photon

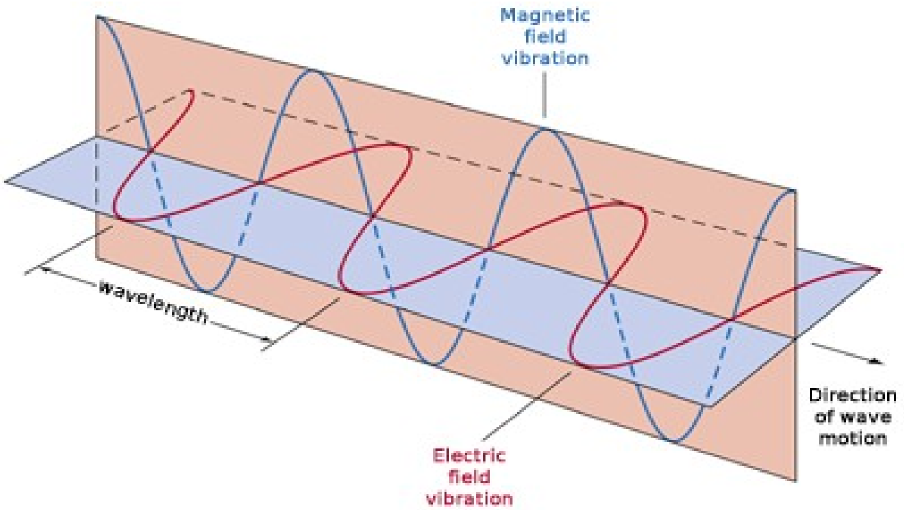
- Electromagnetic radiation can be described in terms of a stream of photons, which are **massless particles** each traveling in a **wave-like pattern** and moving at the **speed of light**.
- Each photon contains a certain amount (or bundle) of energy
- Radio waves have photons with low energies, microwaves have a little more energy than radio waves, infrared has still more, then visible, ultraviolet, X-rays, and ... the most energetic of all ... gamma-rays.



Electromagnetic radiation is the emission and transmission of energy in the form of electromagnetic waves.

Speed of light (c) in vacuum = 3.00×10^8 m/s

All electromagnetic radiation
$\lambda \times \nu = c$



$$f = \frac{c}{\lambda} \qquad c = f\lambda$$

where: f = frequency
c = speed of wave
λ = wavelength of wave

Electromagnetic Radiation Energy

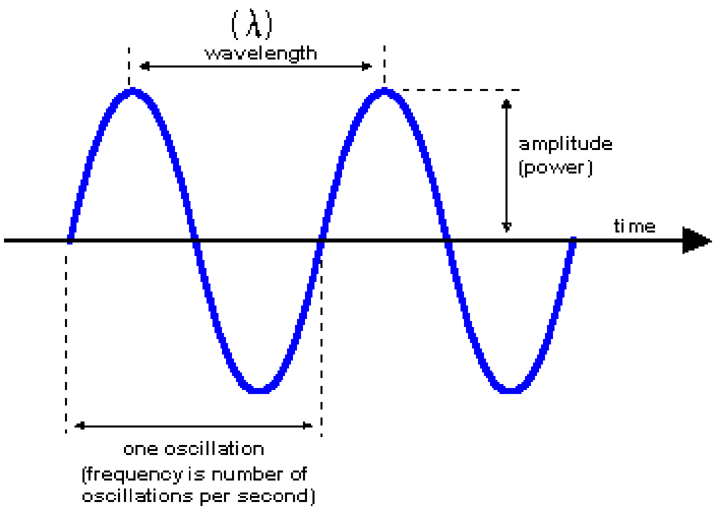
- Electromagnetic radiation energy is :
  - directly proportional to frequency and
  - inversely proportional to the wavelength

$$f \cdot \lambda = c$$

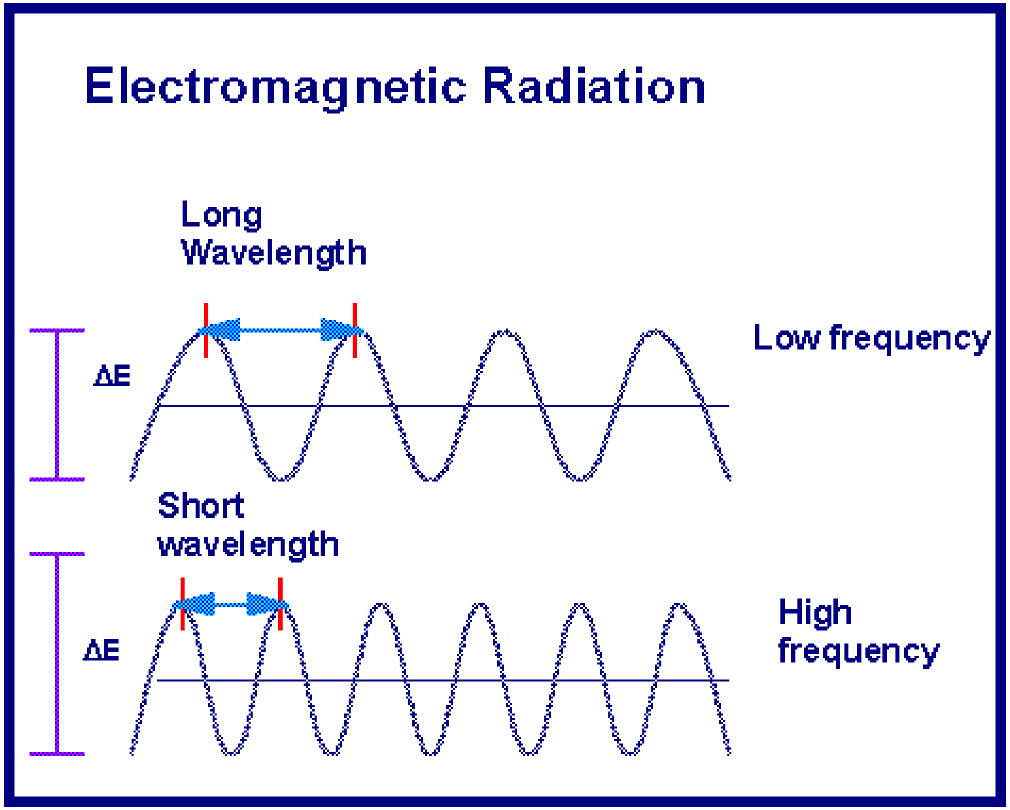
$$E = h \cdot f = h \cdot (c/\lambda)$$

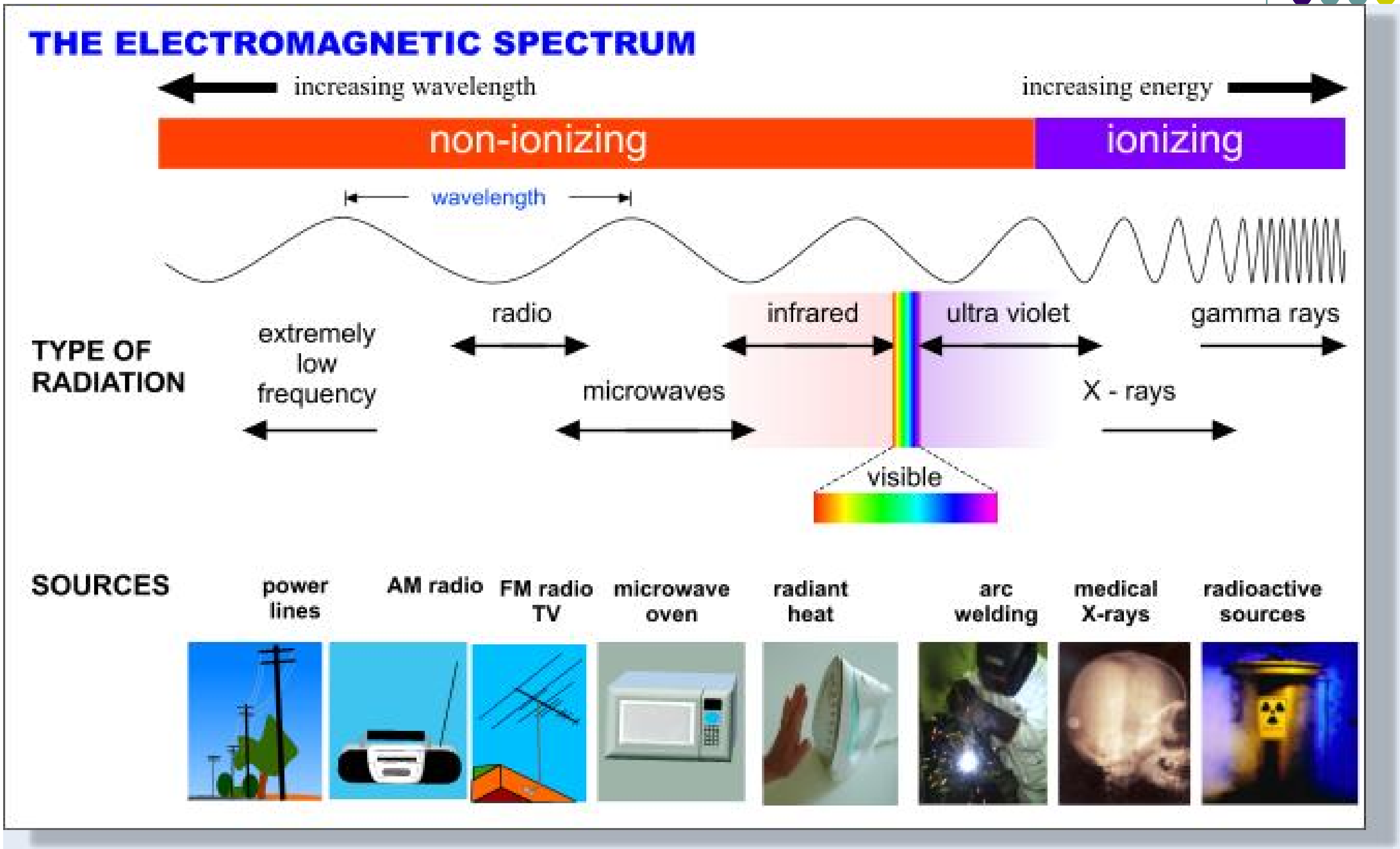
h: Planck's constant = 6.62×10^{-34} Joule.s
= 0.41×10^{-14} eV.s
f: frequency (1/s),
c: speed of light in vacuum (m/s)
λ: wavelength (m)

Frequency - Wavelength Relationship



The higher the frequency, the shorter the wavelength. ($f \cdot \lambda = c$)




THE ELECTROMAGNETIC SPECTRUM
increasing wavelength
increasing energy
non-ionizing
ionizing
wavelength
TYPE OF RADIATION
extremely low frequency
radio
microwaves
infrared
visible
ultra violet
X - rays
gamma rays
SOURCES
power lines
AM radio
FM radio TV
microwave oven
radiant heat
arc welding
medical X-rays
radioactive sources

Non-Ionizing Electromagnetic Waves

Radio Waves

- Radio waves have frequencies from 300 GHz to as low as 3 kHz, and corresponding wavelengths from 1 millimeter to 100 kilometers.
- Like all other electromagnetic waves, they travel at the speed of light.
- Naturally occurring radio waves are made by lightning or, or by astronomical objects.
- Artificially generated radio waves are used for fixed and mobile radio communication, broadcating, radar and other navigation systems, computer networks and innumerable other applications.

Microwaves

- **Microwaves** are radiowaves with wavelengths ranging from as long as one meter to as short as one millimeter.
- Uses
  - Communication
  - Radar
    - Radar uses microwave radiation to detect the range, speed, and other characteristics of remote objects.
  - Astronomy
  - Navigation
  - Heating
    - Microwave ovens
    - Diathermy (In Medicine) :It is commonly used for muscle relaxation.

Infrared

- **Infrared** (**IR**) light is electromagnetic radiation with longer wavelengths than those of visible light.
- Infrared light is used in industrial, scientific, and medical applications.
  - **Night-vision devices** using infrared illumination allow people or animals to be observed without the observer being detected.
  - **Infrared imaging cameras** are used to detect heat loss in insulated systems, **to observe changing blood flow in the skin**, and to detect overheating of electrical apparatus.

Ultraviolet

- **Ultraviolet** (UV) light is electromagnetic radiation with a wavelength shorter than that of visible light, but longer than X-rays.
- The sun is our primary natural source of UV radiation
- The UV spectrum is divided into different zones

UV (40-190 nm), Far UV (190-220 nm), UVC (220-290 nm), UVB(290-320), and UVA (320-400 nm)

- Lower wavelength UV is almost never observed in nature because it is absorbed completely in the atmosphere.
- UVA is needed by humans for synthesis of vitamin D
- Most phototherapy and tanning booths use UVA lamps.
- They are used to kill bacteria and for the sterilization purposes

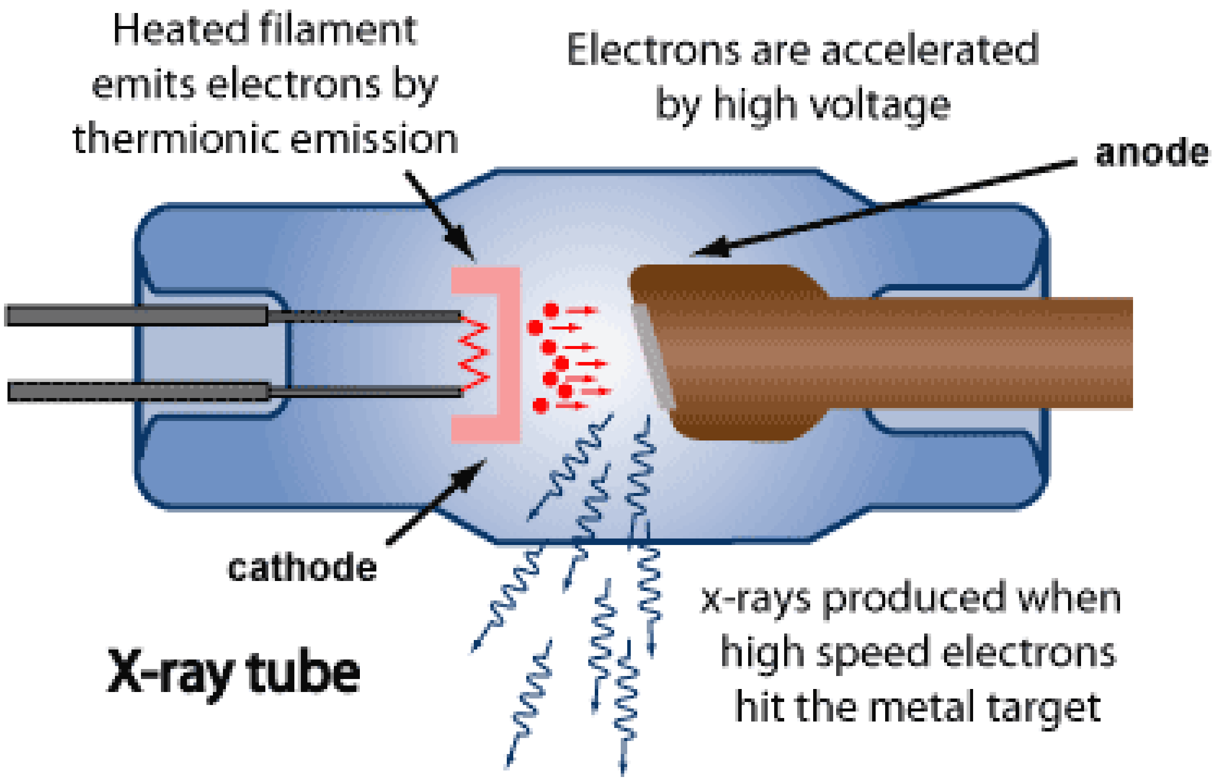
Ionizing
Electromagnetic Waves

X-Rays

Wilhelm Conrad Röntgen

- X-rays were discovered in 1895 by Wilhelm Conrad Röntgen
- He received the first Nobel Prize in Physics in 1901.

X-Rays


Heated filament
emits electrons by
thermionic emission
Electrons are accelerated
by high voltage
anode
cathode
X-ray tube
x-rays produced when
high speed electrons
hit the metal target

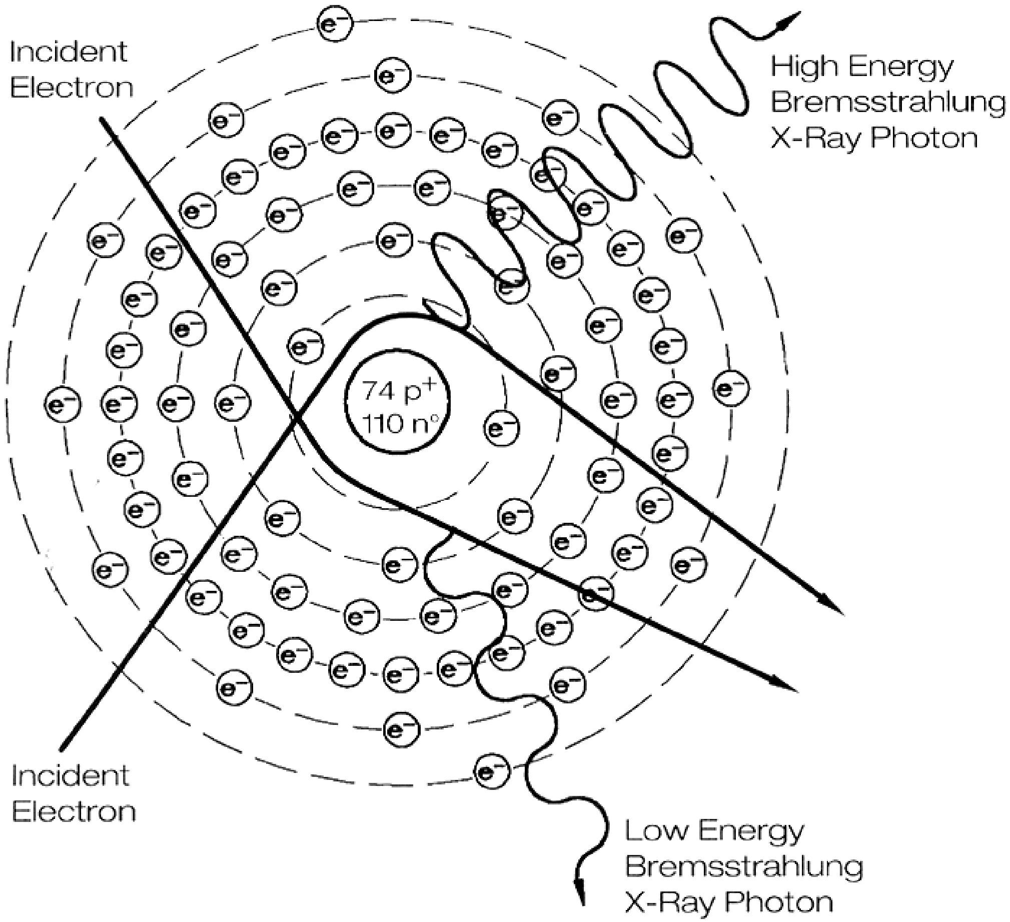
X-Rays

Hand mit Ringen **(Hand with Rings):** print of Wilhelm Röntgen’s first "medical" X-ray, of his wife's hand, taken on 22 December 1895.

Atomic Processes in X-Ray Production

- There are two different atomic processes that can produce X-ray photons.
  - Bremsstrahlung X-Rays ("braking radiation")
  - Characteristic X-Rays

Bremsstrahlung X-Rays

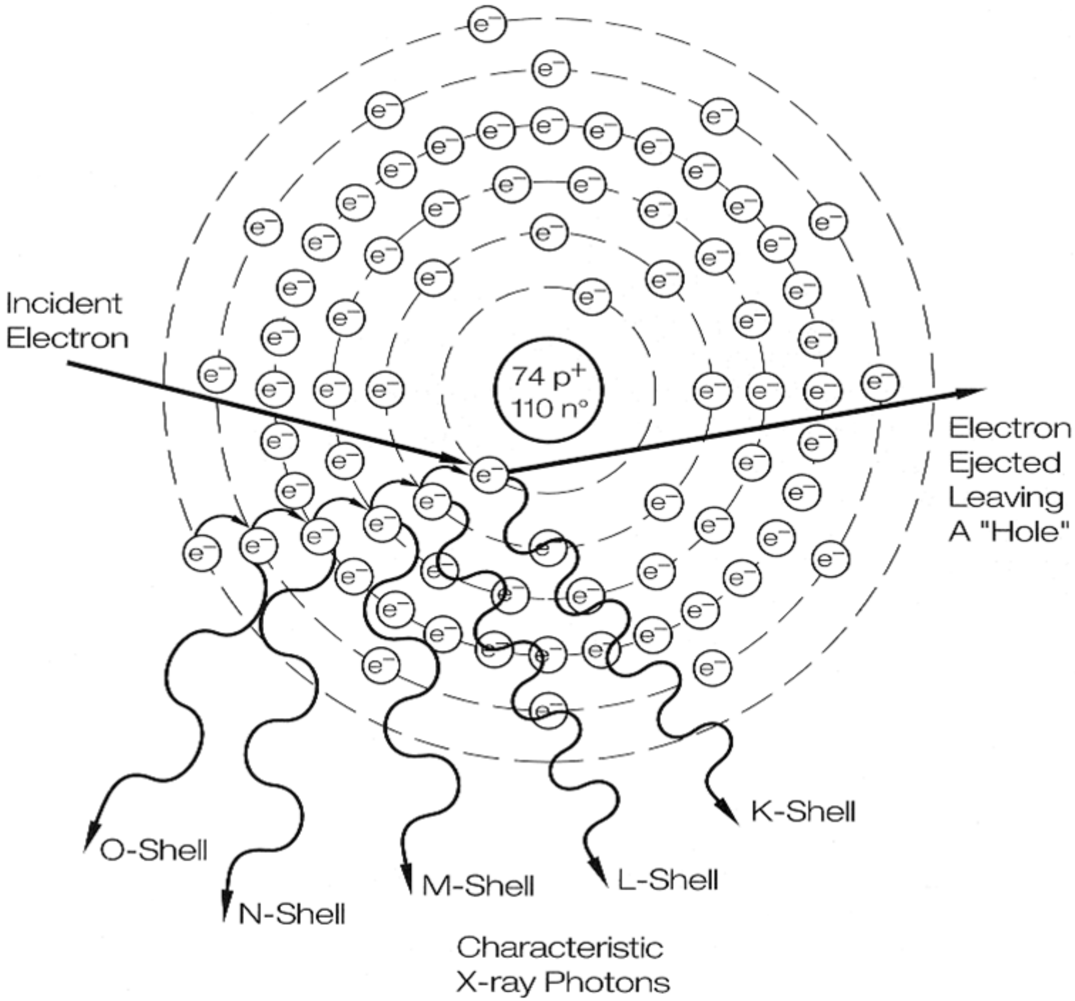


- Bremsstrahlung" means "braking radiation" and is retained from the original German to describe the radiation which is emitted when electrons are decelerated or "braked" when they are fired at a metal target.

Bremsstrahlung X-Rays

- The negatively charged electron slows down after swinging around the nucleus of a positively charged tungsten atom. This energy loss produces X-radiation.
- In the interaction, many photons of different wavelengths are produced.

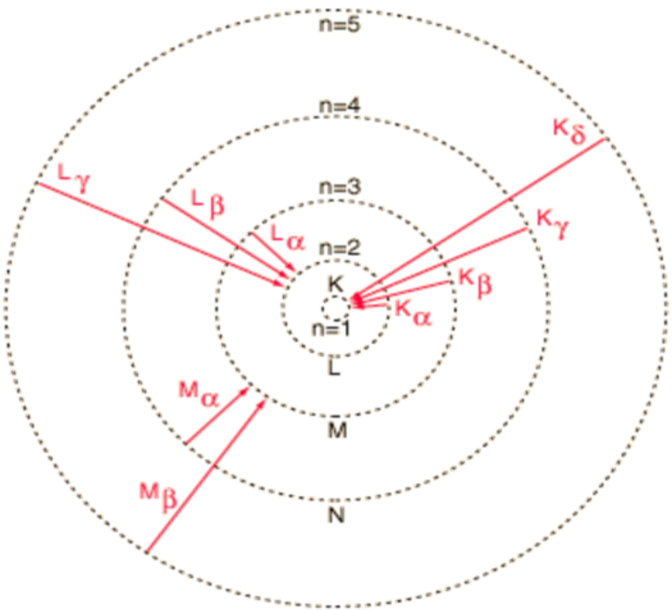
Characteristic X-Rays

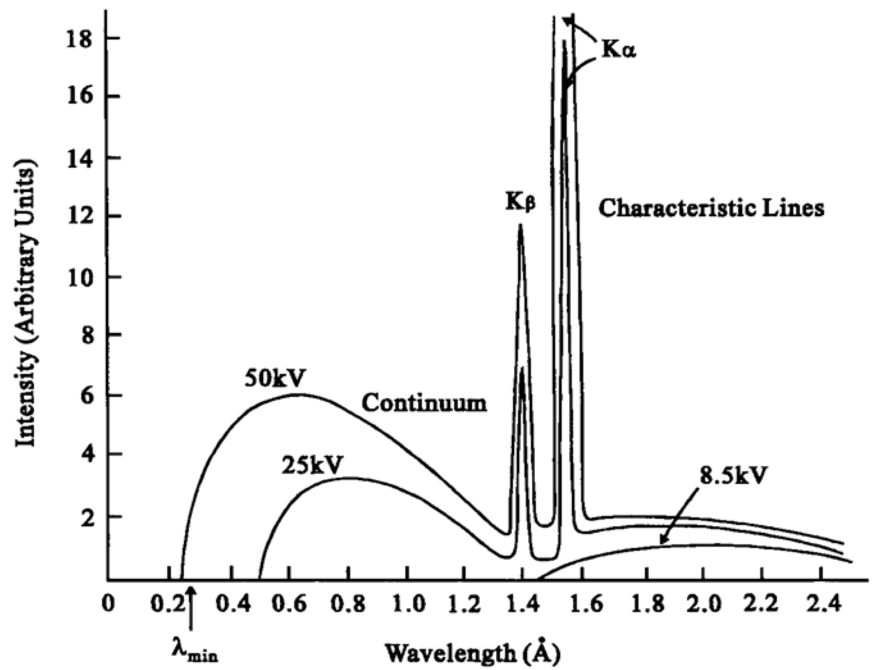


Characteristic X-Rays

- An incoming electron can give a K-shell electron enough energy to knock it out of its energy state. Then, an electron of higher energy (from an outer shell) can fall into the K-shell.
- The energy lost by the falling electron shows up in an emitted x-ray photon.
- Meanwhile, higher energy electrons fall into the vacated energy state in the outer shell, and so on.
- K-shell emission produces higher-intensity x-rays than Bremsstrahlung, and the x-ray photon comes out at a single wavelength.

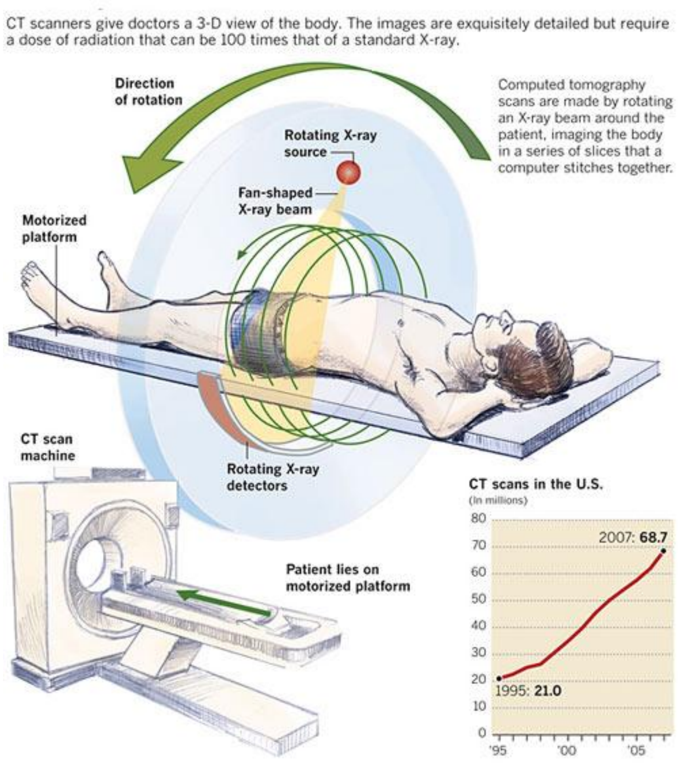
Characteristic X-Rays





When outer-shell electrons drop into inner shells, they emit a **quantized** photon **"characteristic"** of the element. The energies of the characteristic X-rays produced are only very weakly dependent on the chemical structure in which the atom is bound, indicating that the non-bonding shells of atoms are the X-ray source.

X-Rays in Medicine



- **Computed tomography** (**CT scan**) or **computed axial tomography** (**CAT scan**), is a medical imaging procedure that utilizes computer-processed X-rays to produce tomographic images or 'slices' of specific areas of the body.
- **Scanning Electron Microscope**
- X-Ray Sterilisation
- External Beam Radiotherapy
  - X-rays are used to treat tumours

X-Rays in Dentistry

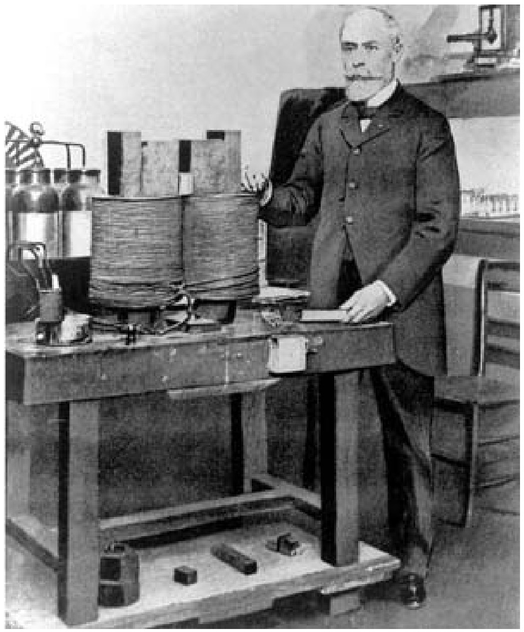
X-rays can reveal

- small cavities between teeth
- cavities hidden by fillings
- infections in the bone
- periodontal disease
- abcesses or cysts
- tumors

Dental CT

- Pre-surgical evaluation for facial or mandibular cosmetic surgery, dental implant design and surgical planning.
- Pre-operative imaging in facial trauma reconstructive surgery.
- Post-operative follow-up after reconstructive or cosmetic surgery.

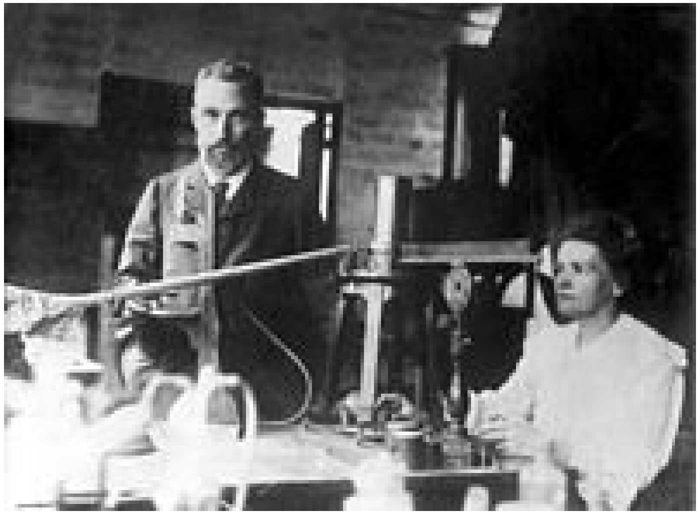
RADIOACTIVITY



Antoine Henri Becquerel
1903 Nobel Physics Prize

- Radioactivity was discovered in 1896 by the French scientist Henri Becquerel.
- He wrapped a photographic plate in black paper and placed uranium salts on it. The result with these compounds was a blackening of the plate.

RADIOACTIVITY



Marie Curie & Pierre Curie
1911 Nobel Prize in Chemistry

- The early researchers also discovered that many other chemical elements besides uranium have radioactive isotopes.
- A systematic search for the total radioactivity in uranium ores also guided **Pierre Curie** and **Marie Curie** to isolate a new element **polonium** and to separate a new element **radium** from barium.

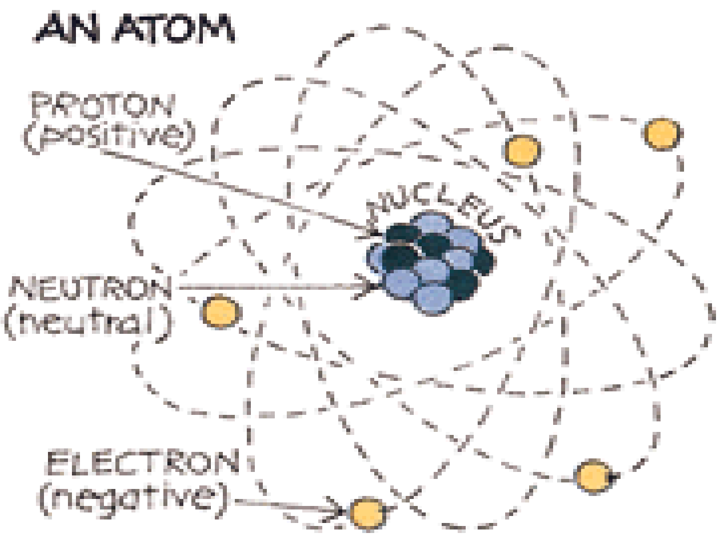
THE ATOM

Atom of an element is symbolized as: ${}_{Z}X^{A}$

N: number of neutrons in the nucleus

Z : Atomic number (number of protons)

Mass number : $A = N + Z$



EXAMPLE:

Iodine element : ${}_{53}I^{131}$

Number of protons (atomic number) : Z= 53,

Mass number $A = N + Z = 131$

Number of neutrons : $N = 131\text{-}53 = 78$

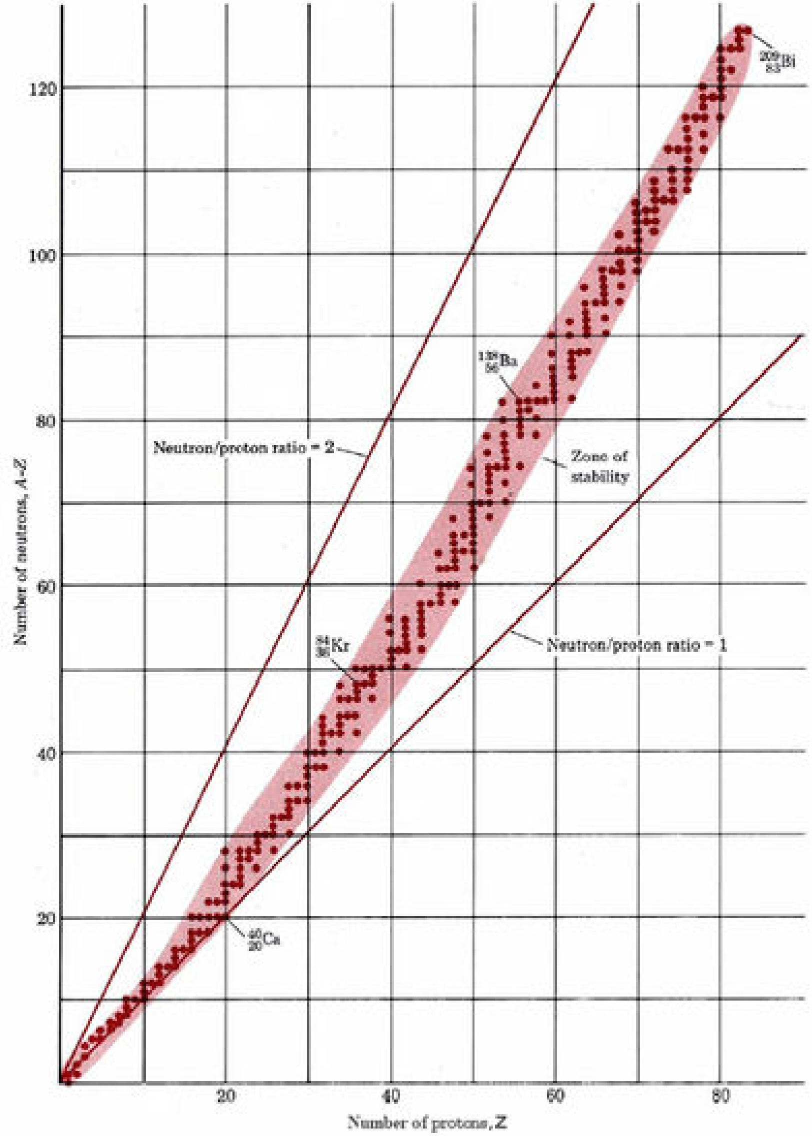
Isotopes

- Each combination of an element with a different number of neutrons is called an **isotope.**
- Carbon 12 and Carbon 14 are both isotopes of carbon, one with 6 neutrons and one with 8 neutrons (both with 6 protons).
- The chemical properties of the different isotopes of an element are identical, but they will often have great differences in nuclear stability.

Radioactivity

- Unstable atoms are **radioactive**: their nuclei change or **decay** by spitting out **radiation**, in the form of particles or electromagnetic waves.
- Natural Radioactive Decay Series:
  - Uranium, radium, and thorium occur in three natural decay series, headed by uranium-238, thorium-232, and uranium-235, respectively.

Zone of Stability



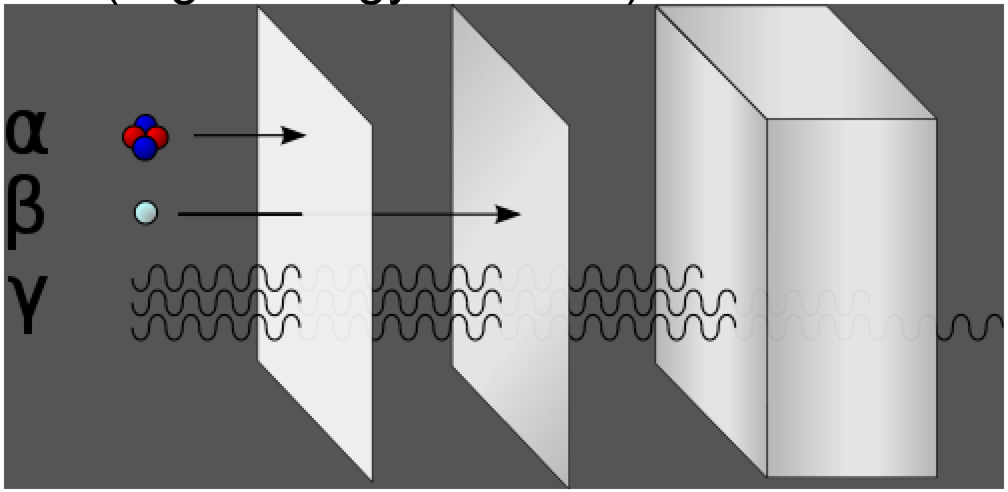
Radioactivity

- Radioactivity is a phenomenon that can not be controlled.
- Radiactivity is unstoppable and can not be slow down.
- The radioactive isotope is called the parent, and the isotope formed by the decay is called the daughter.

Radionuclide Radiations

Radionuclides are unstable nuclides that achieve greater stability by undergoing nuclear transformations. The nuclide may emit:

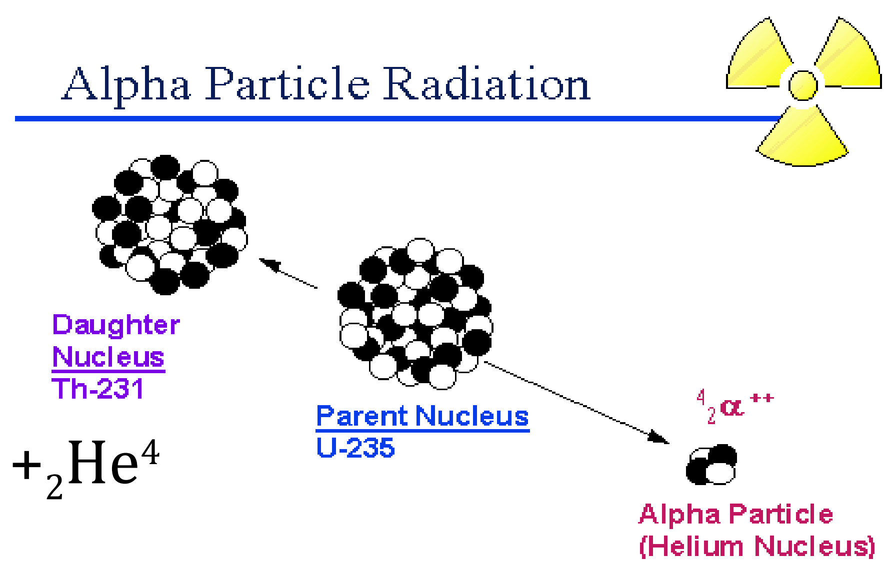
- **alpha particles (α)** (He atom nucleus)
- **Beta particles (β)** (Electrons /Positrons)
- **Gamma rays (γ)** (High Energy Photons)



Paper **Aluminium** **Lead**

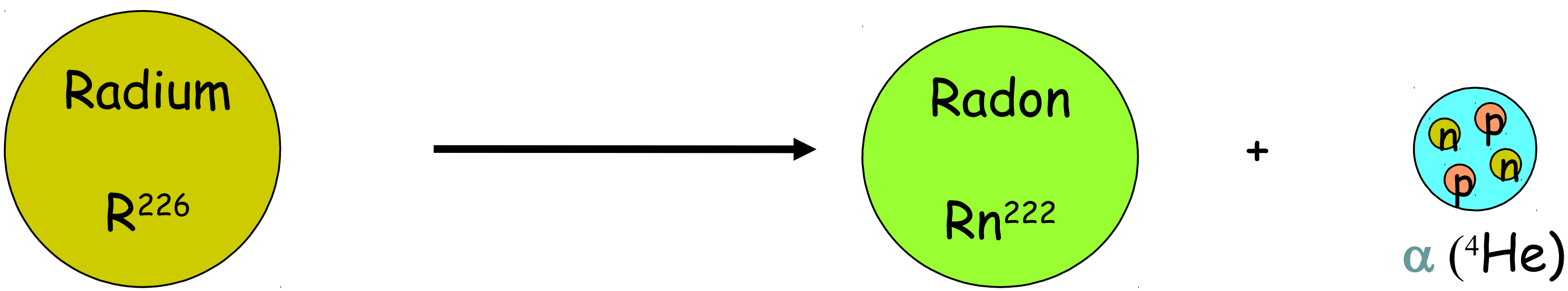
Alpha (α) Particles

- An **alpha particle** consists of two protons and two neutrons and is identical to the nucleus of a helium atom.
- Because of its relatively **large mass and charge**, an alpha particle produces ions in a very localized area. An alpha particle loses its energy each time it produces an ion.
- An alpha particle has a **short range** (several centimeters) in air and cannot penetrate a sheet of paper or the outer layer of skin. Alpha particles are a hazard only if they are taken into the body.
- In contact with fast-growing membranes and living cells, it is positioned for maximum damage.



$$_{92}U^{235} \rightarrow {}_{90}Th^{231} + {}_{2}He^{4}$$

Alpha Particles (α)



88 protons 138 neutrons	86 protons 136 neutrons	2 protons 2 neutrons

The **alpha-particle** (α) is a **Helium nucleus**.

It's the same as the element Helium, with the electrons stripped off !

Beta (β) Particles

- Beta particles (β), fast-moving electrons and positrons.
- Beta particles are much smaller and more penetrating than alpha particles, but their range in tissue is still limited.
- **β^- decay generally occurs in neutron-rich nuclei.**
- If there are more neutrons than protons in the nucleus of an atom, a neutron transforms into a proton

$$n \rightarrow p^+ + \beta^-$$

β^- i.e an electron is released and atomic number increases by 1.

- **In β^+ decay, or "positron emission"**
- If there are more protons than neutrons in the nucleus of an atom, a proton transforms into a neutron

$$p^+ \rightarrow n + \beta^+$$

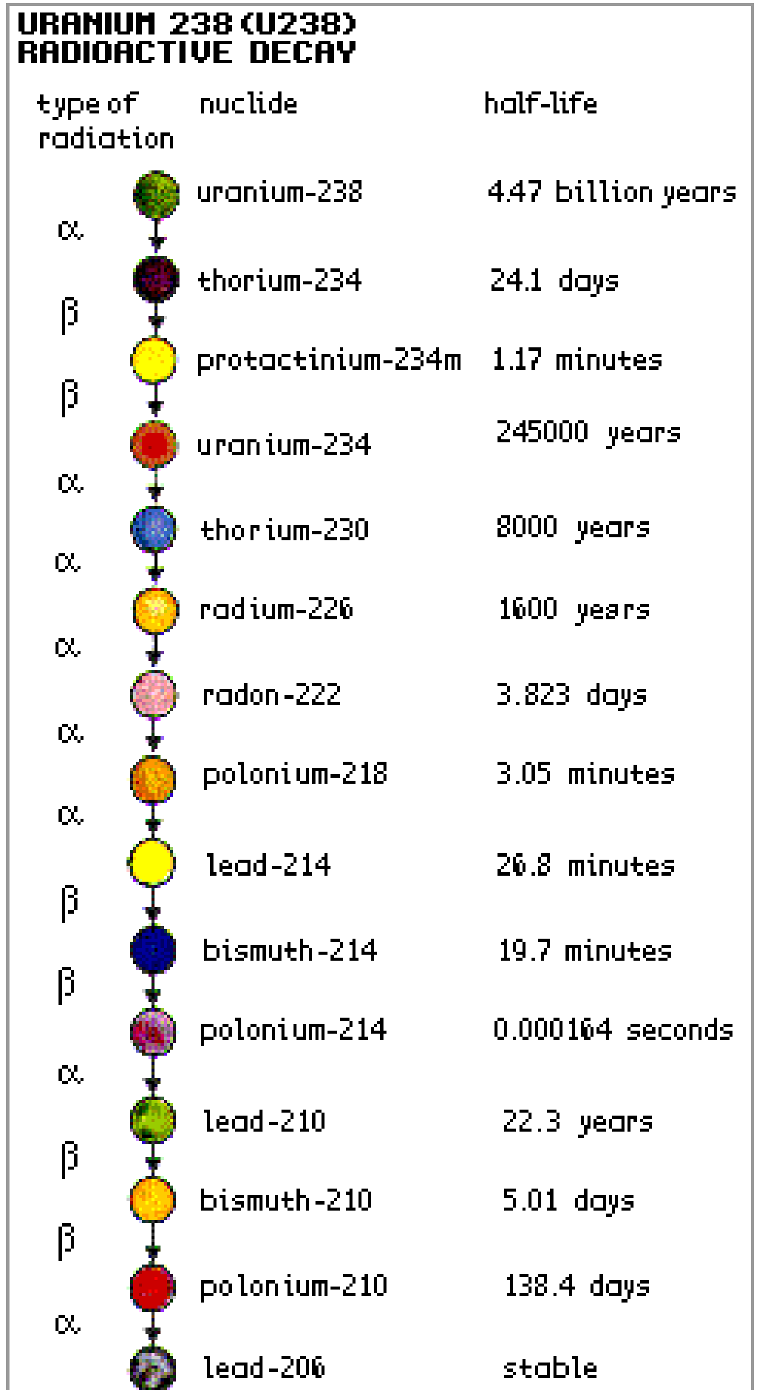
β^+ i.e a positron is released and the atomic number decreases by 1.

Beta (β) Particles

- Although lower energy beta particles are generally a hazard only if taken into the body, high energy beta particles represent an external radiation hazard and can produce significant skin doses.
- Beta particles can pass through a sheet a paper or thin clothing, but are stopped by a thin layer of aluminum foil, plastic, or glass.

Gamma (γ) Rays

- A **gamma ray** is an **electromagnetic radiation** given off by the nucleus of an atom as a means of releasing excess energy, and is released when an atom undergoes decay by emitting an alpha or a beta particle.
- Gamma rays are bundles (quanta) of energy that have no charge or mass and can travel long distances through air (up to several hundred meters), body tissue, and other materials.
- A gamma ray is **extremely penetrating** and represents an external hazard. A gamma ray can pass through a human body without hitting anything, or it may hit an atom and give that atom all or part of its energy.
- While Gamma radiation emitted from atomic nucleus, X-rays emitted from the orbits of the electrons



URANIUM 238 (U238)
RADIOACTIVE DECAY

type of radiation	nuclide	half-life
	uranium-238	4.47 billion years
α		
	thorium-234	24.1 days
β		
	protactinium-234m	1.17 minutes
β		
	uranium-234	245000 years
α		
	thorium-230	8000 years
α		
	radium-226	1600 years
α		
	radon-222	3.823 days
α		
	polonium-218	3.05 minutes
α		
	lead-214	26.8 minutes
β		
	bismuth-214	19.7 minutes
β		
	polonium-214	0.000164 seconds
α		
	lead-210	22.3 years
β		
	bismuth-210	5.01 days
β		
	polonium-210	138.4 days
α		
	lead-206	stable

Parent nucleus $_{33}X^{76}$ forms the daughter nucleus Y as a result of β^- decay. So, what is the atomic and mass number of the nucleus Y?

- According to $n \rightarrow p^+ + \beta^-$
- The number of neutrons in the nucleus decrease by 1, while the number of protons increase by 1.
- Atomic number increase by 1 (Z+1=33+1=34).
- Mass number of the nucleus do not change (A=Z+1+N-1)

Eventually the daughter nucleus is:

$$_{34}\mathbf{Y}^{76}$$

RADIOACTIVE DECAY RATES

- We have labeled all isotopes which exhibit radioactivity as unstable, but radioactive isotopes vary considerably in their degree of instability.
  - Some decay so quickly that it is difficult to detect that they are there at all before they have changed into something else. Others have hardly decayed at all since the earth was formed
- The process of radioactive decay is governed by the uncertainity principle, so that we can never say exactly when a particular nucleus is going to disintegrate and emit a particle.
  - We can, however, give the probability that a nucleus will disintegrate in a given time interval.

LAW OF RADIOACTIVE DECAY

- The **probability** with which a radionuclide decays is a **characteristic and immutable constant** associated with a particular radionuclide.
- This probability cannot be influenced by ambient conditions or their variation.
- The *decay constant* $\boldsymbol{\lambda}$ is the probability of decay of a single radioactive atom per unit of time and is related to the rate of disintegration and the number of radioactive atoms present as

$$-\,dN / dt = \lambda N$$

N is the **number of atoms of the radionuclide** in the source and

t is the **time** (expressed in whatever unit is compatible with the decay constant).

ACTIVITY

- The quantity $-dN / dt$ defines activity as the rate of radioactive decay, expressed in disintegrations per second.
- The activity can be expressed as

$$\mathbf{A = -dN / dt = \lambda N}$$

- Activity represents the total number of disintegrations (decays) of parent nuclei per unit time.

LAW OF RADIOACTIVE DECAY

- Integration of Eq. **$-dN/dt = \lambda N$** yields

$$N = N_0 \cdot e^{-\lambda t}$$

N_0 is the initial number of radioactive atoms in the source,

e is the natural base of logarithms, and

N is the number of radioactive atoms present at any time t.

$$-dN = \lambda N dt \qquad (2.2)$$

Denklem (2.2)'nin integralini alırsak;

$$\frac{dN}{N} = -\lambda dt$$

$$\int_{No}^{N} \frac{dN}{N} = -\int_{to}^{t} \lambda dt$$

$$\ln N - \ln N_0 = -\lambda(t - t_0)$$

$$N = N_0 e^{-\lambda(t-t_0)} \qquad (2.3)$$

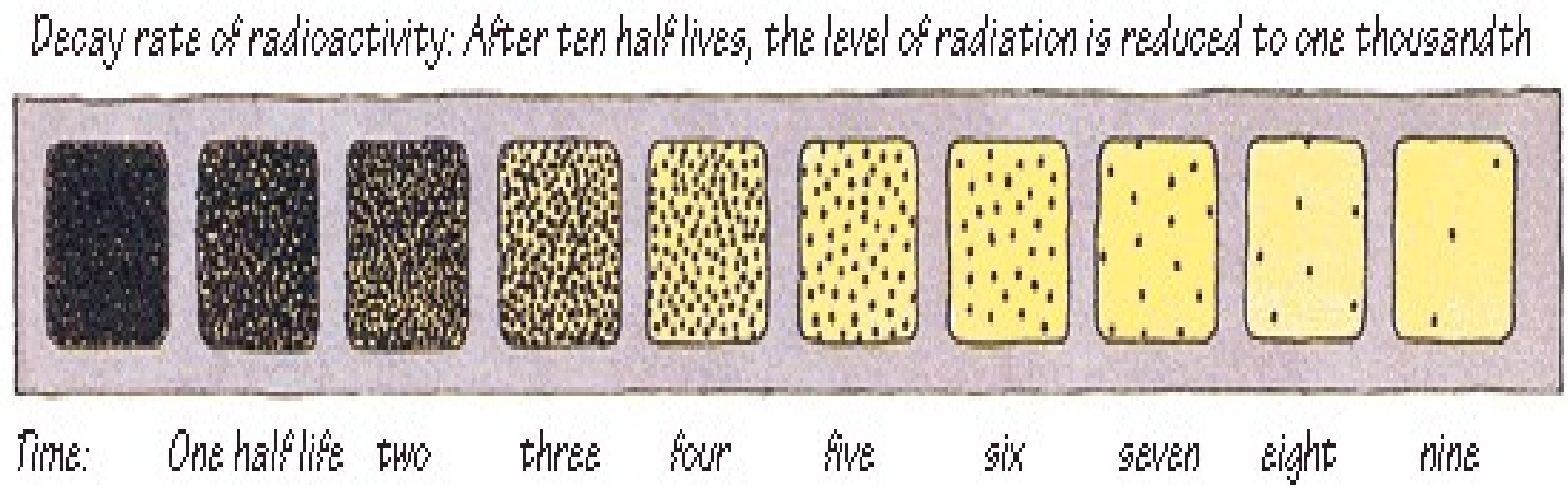
elde edilir.

İfade (2.3)' de N_o belirli bir t anında radyoaktif çekirdeklerin sayısıdır. Bu zaman genelde başlangıç (t=0) anı olarak alınır. t=0 alınırsa denklem (2.3) ;

$$N = N_0 e^{-\lambda t} \qquad (2.4)$$

HALF- LIFE

- The **<u>"half-life"</u>** is the time it takes for ***half the atoms*** of a radioactive substance to decay.



HALF- LIFE

- For example, suppose we had 20,000 atoms of a radioactive substance. If the half-life is 1 hour, how many atoms of that substance would be left after:

Time	#atoms remaining	% of atoms remaining
1 hour (one half-life) ?	**10,000**	**(50%)**
2 hours (two half-life) ?	**5,000**	**(25%)**
3 hours (three half-life) ?	**2,500**	**(12.5%)**

HALF- LIFE

- If we let $N = N_0/2$ and $t = T_{1/2}$ (where $T_{1/2}$ is taken to be the time required for a source to decrease its activity to $N_0/2$), substitution into Eq. $N = N_0 \, . \, e^{-\lambda t}$ gives, on rearrangement,

$$N_0/2 = N_0 \, . \, e^{-\lambda T_{1/2}}$$ ve

$$N_0(1/2) = N_0 . \, e^{-\lambda T_{1/2}}$$

$$1/2 = e^{-\lambda T_{1/2}}$$ (apply Log function)

$$\ln 1 - \ln 2 = - \lambda \, . T_{1/2}$$

$$\ln 2 = \lambda \, . T_{1/2}$$

$$0,693 = \lambda \, . T_{1/2}$$

Eventually **Half –life** is: $T = 0,693 / \lambda$

AVERAGE LIFE TIME (τ)

- The average lifetime of a radioactive particle before decay.
- It is inverse of the decay constant λ.
- It is simply:

$$\tau = 1/\lambda \quad \text{or} \quad \tau = 1.44 \times T_{1/2}$$

BIOLOGICAL HALF-LIFE

- Biological half life is the time it takes for organic or inorganic substances to be halved in the body.
- If a radioisotope is in a living organism it may be excreted so that it no longer is a source of radiation exposure to the organism.
- Besides decay rate of radionuclids, physiological excretion processes are also important factors in determining the impact of radioisotope in a living organism.

EFFECTIVE HALF-LIFE

- **Effective half-life** denotes the halving of radioactive material in a living organism by means of radioactive decay and biological excretion.
- Though the biological half-life cannot be expected to be as precise as the physical half-life, it is necessary to compute an effective half-life from:

$$1/T_{\text{Effective}} = 1/T_{\text{Physical}} + 1/T_{\text{Biological}}$$

If the physical half-life of 1 g of Radium-226 is 1620 years, then calculate its activity. $_{86}Ra^{226}$

- Atomic number is Z = 86 and Mass number is A= 226
- In a 1 mol of **Ra sample (226 g)** there are **6.023×10^{23}** (Avogadro's number) **radioactive atom nuclid**
- Then in a 1g of Ra sample there are;
  $N = 6.023 \times 10^{23} / 226 = 2.65 \times 10^{21}$ radioactive atom nuclid
- Physical half-life is 1620 years:
  $\mathbf{T_{1/2}} = 1620 \times 365(\text{day}) \times 86400\ (24 \times 60 \times 60\ \text{second})$
  $= 51 \times 10^{9}$ sec
- The decay constant is: $\boldsymbol{\lambda} = \mathbf{0.693} / \mathbf{T_{1/2}} = 0.693 / 51 \times 10^{9}$
  $= 13.5 \times 10^{-12}$ sec
- As a result, the number of decaying radioactive nuclid in 1 g of Ra^{226} in a second is:
- $\mathbf{A} = \boldsymbol{\lambda}\, \mathbf{N} = (13.5 \times 10^{-12}).\ (2.65 \times 10^{21}) = 3.7 \times 10^{10}$ atoms/sec
  ("Becquerel" = Bq)
- **This value is also equal to 1 Curie (1 Ci).**

^{131}I isotope is used in thyroid examinations.

Its physical half-life and biological half-life are 8 days and 15 days respectively. So, what is the effective half-life of this substance?

$$1/T_{Effective} = 1/T_{Physical} + 1/T_{Biological}$$

$$T_E = T_P x T_B / T_P + T_B$$

$$= 8 \times 15 / 8+15$$

$$= 5.2 \text{ days}$$

Radiation Units

Radiation Energy
Electronvolt (eV)

- $E = h.\upsilon$

  h (planck's constant) = 6.62608 $x10^{-34}$ Joule.second

  υ (frequency) = 1/ second

- **1 eV (electronvolt):** The amount of energy gained (or lost) by the charge of a single electron moved across an electric potential difference of one volt.

  - 1 eV = 1.6 x 10^{-19} Joule(J)

Radioactivity
Becquerel (Bq)

- Bq: becquerel (in SI, the International System of Units)

1 Bq = 1 atom decaying / 1 second

- The conventional unit Curie (Ci) is roughly the activity of 1 gram of the radium isotope ^{226}Ra, a substance studied by the Curies.

  1 Ci = 3.7×10^{10} Bq

Ion Dose
Roentgen (R)

- Ionizing rays ionize the air along their paths. **Ion dose** is the amount of electric charge generated by ionizing radiation per kilogram of air.

- 1 R (roentgen) = 2.58 x 10^{-4} Coulomb (C)/kg
  - 0^{0}C and 760 mmHg pressure

- **Roentgen unit denotes only the ionization of the air.**

Absorbed Energy Dose
Gray (Gy)

- **Absorbed energy dose** is a measure of the energy deposited in a medium by ionizing radiation per unit mass.
- It is equal to the energy deposited per unit mass of medium, which may be measured as **joules per kilogram** and represented by the equivalent SI unit, **Gray (Gy).**
- 1 Gy = 1 J/kg
- Antiquated CGS unit
  - rad = radiation absorbed dose
  - 1 rad = 0.01 Gy

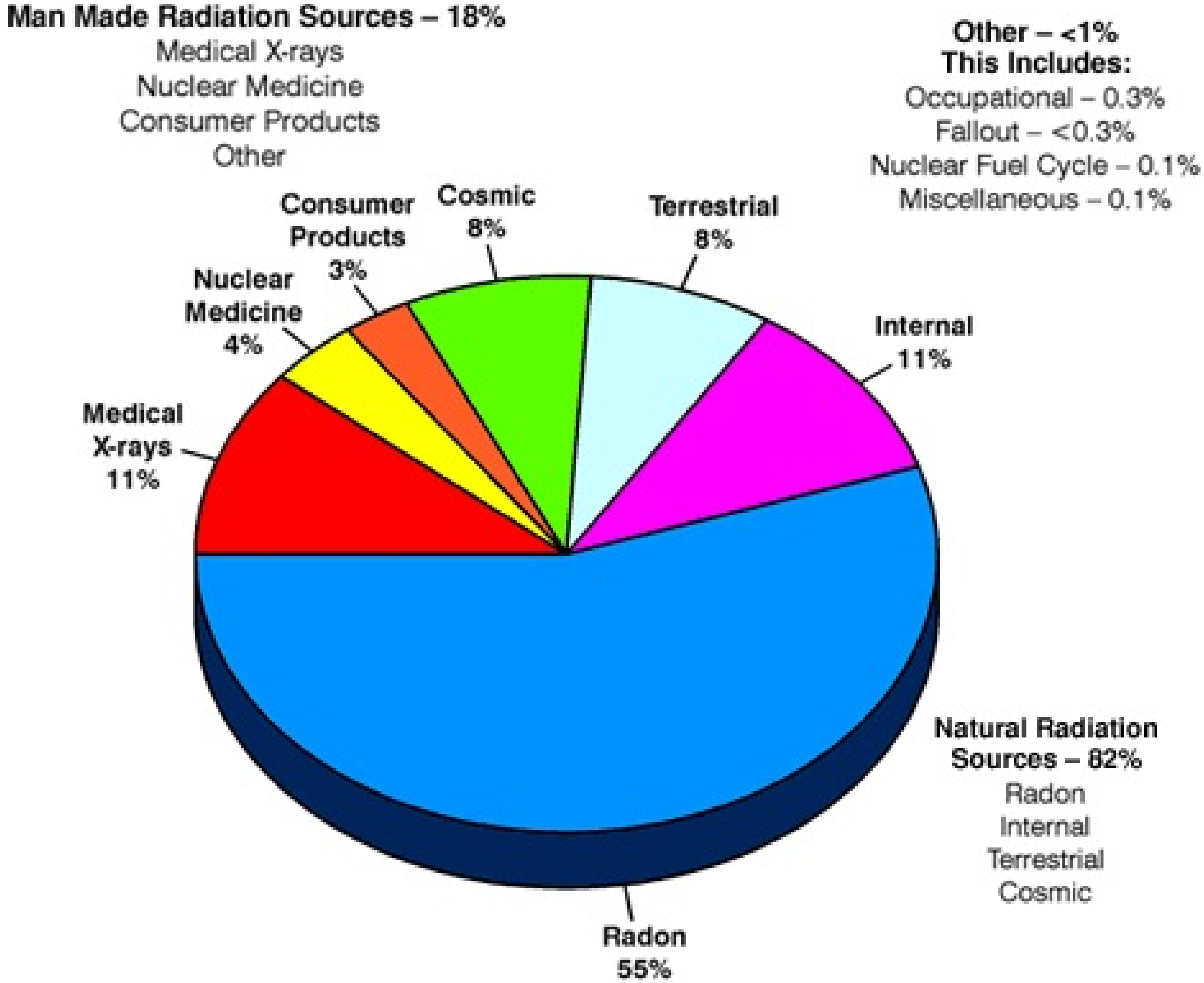
Equivalent Dose
Sievert (Sv)

- The **equivalent absorbed radiation dose**, usually shortened to **equivalent dose.**
- **Equivalent dose** is a computed average measure of the radiation absorbed by a fixed mass of biological tissue, that attempts to account for the different biological damage potential of different types of ionizing radiation.
- It is therefore a more significant quantity for assessing the health risk of radiation exposure.
- The biological risk of exposure to radiation is measured using the SI unit **sievert (Sv).**
- the conventional unit is **rem** (<u>r</u>öntgen <u>e</u>quivalent <u>m</u>an)
  - 1 Sv = 100 rem

TERM	UNITS	
	CGS (Conventional)	**SI**
ACTIVITY (Radioactive Decay)	**Curie (Ci)=** $3.7x10^{10}$ atoms decaying / 1 sec	**Becquerel (Bq);** 1 atom decaying/1 sec
ION DOSE	**Roentgen (R);** the dose of X or γ radiation required to produce $2.58x10^{-4}$ Coulomb ion pairs in 1kg of dry air (0^0C and 760 mmHg pressure).	**Coulomb / kilogram (C/kg)** ; the dose of X or γ radiation required to produce 1 Coulomb (+) and (-) ions in 1kg of dry air (0^0C and 760 mmHg pressure).
ABSORBED ENERGY DOSE	**radiation dose (rad);** is defined as a dose of 10^{-2} J of energy per kilogram of the given material.	**Gray (Gy)** ; which is defined as a dose of one joule (J) per kilogram.
EQUIVALENT DOSE	**roentgen equivalent man (rem);** the dose of any radiation having the same biological effect of 1 R X or γ-rays.	**Sievert (Sv);** the dose of any radiation having the same biological effect of 1Gy X or γ-rays.

Sources of Radiation Exposure

Ionizing Radiation Exposure to the Public



Natural Radiation Sources

- Cosmic (Space) Radiation
- Terrestrial Radiation

    Radiation from the elements in the ground

Cosmic Radiations

- Outer space is full of various types of radiation, such as heavily charged particles and gamma rays.
- Fortunately, earth has an atmosphere that helps absorb and filter them out, which protects us from high doses of cosmic radiation.
- The dose of cosmic radiation that we receive varies depending on the altitude which we live.
  - Since air is thinner at higher elevations, less cosmic radiation is filtered out than it is at lower altitudes with thicker air.
  - Those living in high (altitutes) residential areas, flight personnel receive higher doses of radiation.

Terrestrial Radiation

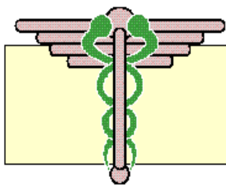
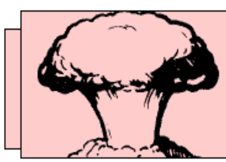
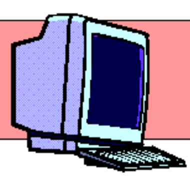
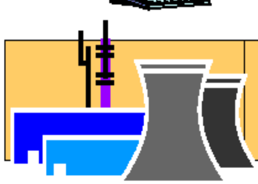
- The high-energy cosmic rays continuously produces new radioactive substances in the upper layers of the atmosphere.
  - Among these, particularly tritium ($_{3}H$) and carbon ($_{14}C$), and a variety of radioisotopes, come down to the earth by air flows or rains.
- Radioactive substances in the earth's crust - thorium, uranium-actinium and uranium-radium radioisotope series.

Terrestrial Radiation

- $_{40}K$ potassium radioisotope naturally exists in the soil, via nutrients and water these isotopes enter human body and emit radiation internally.
- Radon is a radioactive gas. It comes from the natural decay of uranium that is found in nearly all soils and rocks. It typically moves up through the ground to the air above and into the buildings.
- Radon contribution in 'natural radiation exposure' constitutes an important part.
  - There are several proven methods to reduce radon in buildings, but the one primarily used is a vent pipe system and fan, which pulls radon from beneath the building and vents it to the outside.
  - Sealing cracks and other openings makes this kind of system more effective and cost-efficient.

MANMADE RADIATION SOURCES

Radiation from Manmade Sources

	Source	mrem/year
	Medical	90
	Fallout	5
	Consumer products	1
	Nuclear power	0.3

Medical Applications of Ionizing Radiation Sources

- Ionizing radiation has two very different uses in medicine:
  - diagnosis
  - therapy

Medical Applications of Ionizing Radiation Sources

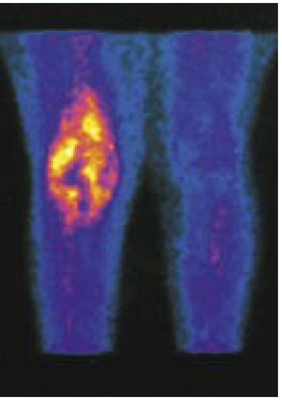
Diagnosis

- **Diagnostic Radiology**: In medicine for diagnostic purposes a particular organ or part of the body is imaged by **X-rays** to help the physician diagnose disease or damage in the body.

- **CT examinations** are significant contributors to collective dose from medical diagnosis.
- **Interventional radiology** gives the highest doses. By injecting a radio-opaque contrast agent into the organ (blood vessel in angiography) and imaging using X-ray based techniques.

Medical Applications of Ionizing Radiation Sources

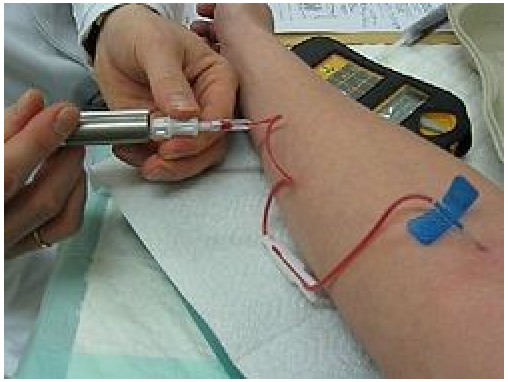
Diagnosis



Scintigram of a patient with a knee prosthesis

- **Nucleer Medicine:** A much less common diagnostic procedure involves the **administration of radionuclides** to patients so that detectors outside the body can be used to observe how organs are functioning.
  - The radionuclides emit gamma rays.
  - A special detector called gamma camera is used to observe how the organs or tissue function or how quickly the radionuclide moves.

Gamma Camera



Medical Applications of Ionizing Radiation Sources

Radiotherapy

- When radiation beams are used to treat patients, the procedure is called radiotherapy.
- This technique is used to cure cancers or at least to alleviate the most distressing symptoms, by killing the cancerous cells.
- A beam of high energy X rays, gamma rays or electorns is directed towards the diseased tissue so as to give it a high dose while sparing the sorrounding healthy tissue.

Biological Effects of Radiation

Biological Effects of Radiation

- **Biological effect begins with the ionization of atoms. The mechanism by which radiation causes damage to human tissue, or any other material, is by ionization of atoms in the material.**
  - Ionizing radiation absorbed by human tissue has enough energy to remove electrons from the atoms that make up molecules of the tissue.
  - When the electron that was shared by the two atoms to form a molecular bond is dislodged by ionizing radiation, the bond is broken and thus, the molecule falls apart. This is a basic model for understanding radiation damage.

Biological Effects of Radiation

- The degree and type of health effects of radiation is depend on to the following factors:
  - Dose of radiation
  - Duration of radiation
  - Type of ionizing rays
  - The sensitivity and type of the target tissue
  - Age of the radiated subject

Biological Effects of Radiation

- Biological Effects of Radiation may be divided into two classes:
  - Somatic
  - Genetic (Heritable)

Somatic Effects

- **Somatic effects appear in the exposed person.** Somatic effects may be divided into two classes based on the rate at which the dose was received.
  - **Prompt somatic effects**
  - **Delayed somatic effects**

Prompt somatic effects

- **Prompt somatic effects** are those that occur soon after an acute dose (typically 0.1 Gy or greater to the whole body in a short period of time).
  - One example of a prompt effect is the temporary hair loss which occurs about three weeks after a dose of 4 Gy to the scalp.
  - An instantaneous absorbed dose of 5 Gy to the skin would probably cause erythema — painful reddening of the skin — within a week or so, whereas a similar dose to the reproductive organs might cause sterility.
  - These types of effect are called **deterministic effects**: they occur only if the dose or dose rate is greater than some threshold value, and the effect occurs earlier and is more severe as the dose and dose rate increase.
  - Deterministic effects in an individual can be identified clinically to be the result of radiation exposure.

Delayed somatic effects

- **Delayed somatic effects** are those that may occur years after radiation doses are received. Among the delayed effects thus far observed have been an increased potential for the development of cancer and cataracts.
  - If the absorbed dose is lower, or is delivered over a longer period of time, there is a greater opportunity for the body cells to repair, and there may be no early signs of injury.
  - Even so, tissues may still have been damaged in such a way that the effects appear only later in life.
  - These types of effects are called **stochastic efffects**: they are not certain to occur,but the likelihood that they will occur increases as the dose increases.
  - Because radiation is not the only known cause of most of these effects, it is normally impossible to determine clinically whether an individual case is the result of radiation exposure or not.

Genetic, or *heritable* effects

- **Genetic, or *heritable* effects appear in the future generations of the exposed person as a result of radiation damage to the reproductive cells**.
  - Genetic damage arises from irradiation of the testes and ovaries. Ionizing radiation can induce mutations in these cells or in the germ cells that form them, mutations which may give rise to harmful effects in future generations.

Cellular Sensitivity to Radiation.

Not all living cells are equally sensitive to radiation. Those cells which are actively reproducing are more sensitive than those which are not.

- Lymphocytes (white blood cells) and cells which produce blood are constantly regenerating, and are therefore the most sensitive.
- Reproductive and gastrointestinal cells do not regenerate as quickly and are less sensitive.
- Nerve and muscle cells are the slowest to regenerate and are the least sensitive

Organ Sensitivity to Radiation

- The sensitivity of the various organs of the human body correlate with the relative sensitivity of the cells from which they are composed.
  - For example, since the blood-forming cells are one of the most sensitive cells because of their rapid regeneration rate, the blood-forming organs are some of the most sensitive organs to radiation.
    - Bone marrow, ovaries and testicles (reproductive organs), gastro-intestinal and skin epithelium are the most sensitive organs
  - Muscle and nerve cells are relatively insensitive to radiation, and therefore, so are the muscles and the brain.
    - Liver, kidney, muscles, bones, and connective tissues are resistant to radiation

Radiation Safety

Three Effective Strategies

TIME

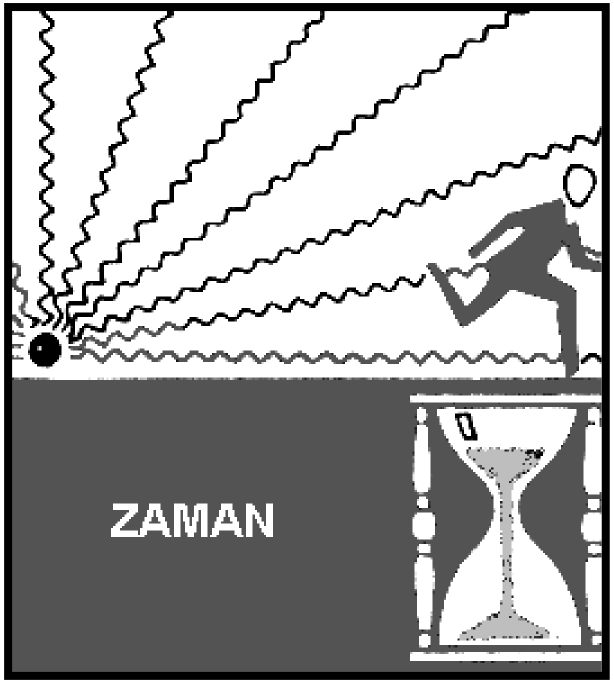
SHIELD

DISTANCE

Three Effective Strategies -Time-

- Minimize the time and you will minimize the dose

- **Dose = (Dose Intensity) x (Time)**
- Thus, in a 50 mSv /h radiation dose area exposure dose is:
  - 50 mSv per hour ,
  - 100 mSv in 2 hours,
  - 150 mSv in 3 hours, etc.

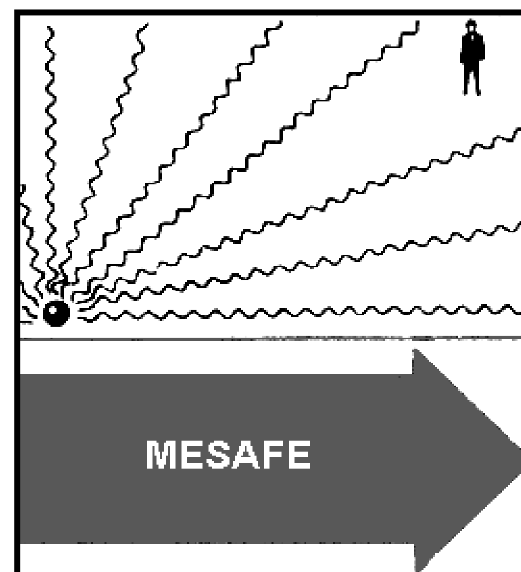


Three Effective Strategies
-Time-

- The shorter the time in a radiation field, the less the radiation exposure you will receive.
- Work quickly and efficiently.
- Plan your work before entering the radiation field.

Three Effective Strategies
-Distance-

- Radiation intensity is inversely proportional to the square of the distance to the radiation source.
- Doubling the distance from the source can reduce your exposure intensity by 25%.
  - For example, a person who is 4 m far from a radiation source will be exposed to 1/4 of exposure intensity of the one who is 2m away from the same source.



- $I_1 . R_1^2 = I_2 . R_2^2$

  I= intensity, R = distance

Three Effective Strategies
-Distance-

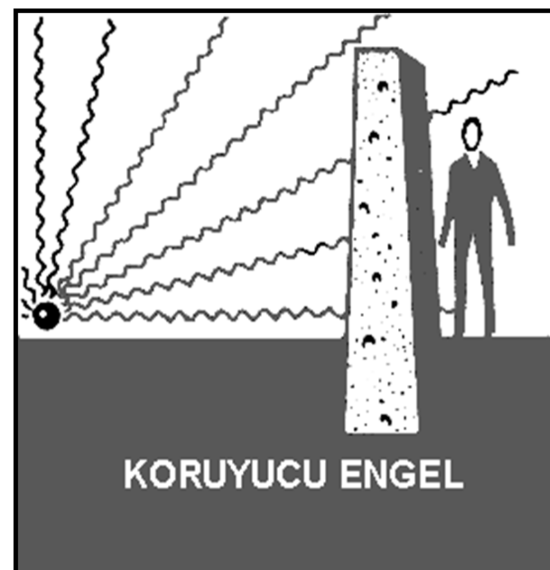
- The farther a person is from a source of radiation, the lower the radiation dose.
- Levels decrease by a factor of the square of the distance.
- Do not touch radioactive materials.
- Use remote handling devices, etc., to move materials to avoid physical contact.

Three Effective Strategies -Shielding-

- Plexiglas, concrete and lead are effective in shielding radiation exposure.
- It is important to use the proper shielding for the type of radioactive material present.
- The decrease in the intensity of radiation is exponential.
  - $I_2 = I_1 . e^{-\mu x}$ μ : linear absorption coefficient

    x : thickness.

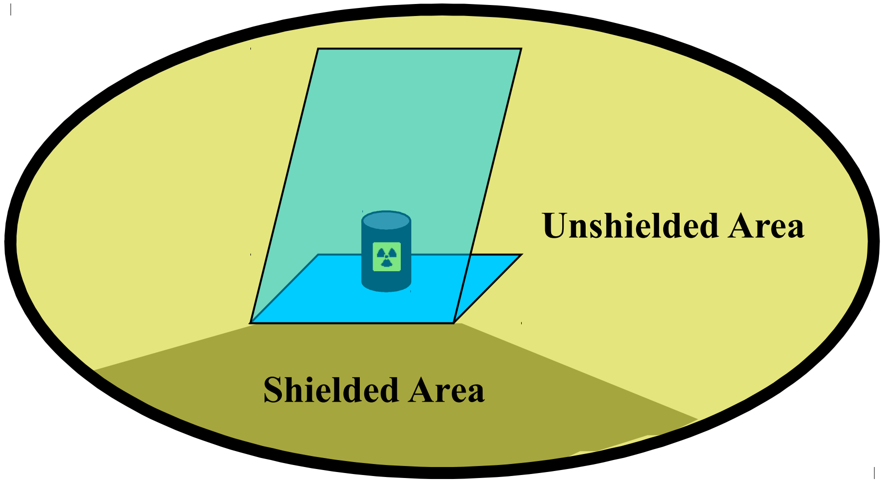
In effective shielding Half Value Layer (HVL) and Tenth Value Thickness (TVT) are important parameters.



HVL = 0,693 / μ TVT = 2,303 / μ

Three Effective Strategies -Shielding-

- Placing radioactive materials closer to the shield maximizes the protected area.
- Effective shielding provides protection in all directions.



Approximate HVL for Various Materials when Radiation is from a Gamma Source

	Half-Value Layer, mm (inch)				
Source	**Concrete**	**Steel**	**Lead**	**Tungsten**	**Uranium**
Iridium-192	44.5 (1.75)	12.7 (0.5)	4.8 (0.19)	3.3 (0.13)	2.8 (0.11)
Cobalt-60	60.5 (2.38)	21.6 (0.85)	12.5 (0.49)	7.9 (0.31)	6.9 (0.27)

- Lead shielding will reduce the intensity of x-rays and gamma rays being emitted from a source of radiation.
- To reduce exposure by a certain desired percent, lead shielding must be a certain thickness for each type of emitter.

Radiation Protection Standards

The basic radiation protection standards recommended by International Commission on Radiological Protection (ICRP) are:

ICRP Recommended Dose Limits for One Year

Body Part	Occupational	General Public
Whole Body	20 mSv	1 mSv
Lens of the Eye	150 mSv	15 mSv
Skin	500 mSv	50 mSv
Hands and Feet	500 mSv	—

Personal Protective Equipment

- Lead apron
- Thyroid shield
- Glasses
- Concrete
- Lead front

To prevent cracking of lead layer of aprons they should be hanged rather than bended.

Radiation Safety -Laboratory Rules-

- Smoking, eating, and drinking are not permitted in radionuclide laboratories.
- Food and food containers are not permitted in the laboratory.
  - Do not use refrigerators for common storage of food and radioactive materials.

Radiation Safety -Laboratory Rules-

- Protective clothing shall be worn when working with radioactive materials. This includes laboratory coats, gloves, and safety glasses.

- Dosimeters shall be worn when working with relatively large quantities of radionuclides which emit penetrating radiation

Radiation Safety
-Laboratory Rules-

- All containers of radioactive materials and items suspected or known to be contaminated shall be properly labeled with tape or tagged with the radiation logo and the word "RADIOACTIVE".

- All contaminated waste items shall be placed in a container specifically designed for radioactive waste.

How Can You Detect Radiation?

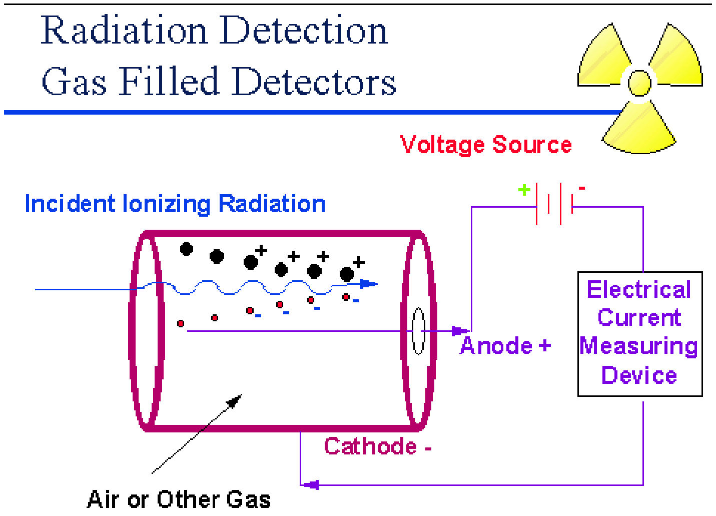
- Radiation cannot be detected by human senses.
- A variety of handheld and laboratory instruments is available for detecting and measuring radiation.

Radiation measurement systems

1. Gas Detectors (ionization chambers, Geiger-Müller detectors)

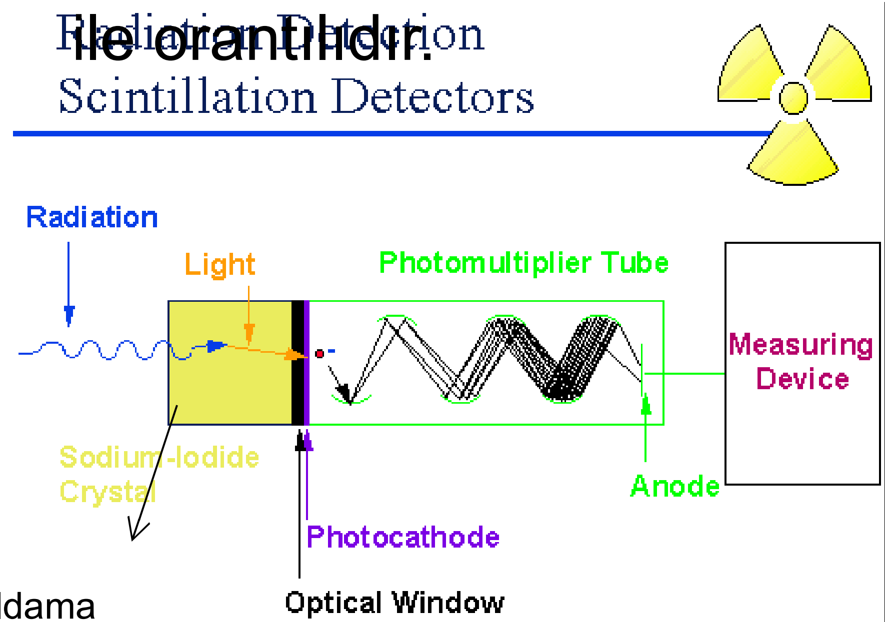
Alfa, Beta duyarlığı fazla, gama duyarlığı azdır. Yüksek sayım hızı alınmaz.

- Yüklerin deşarjı sırasında detektöre giren başka ışınlar sayılamaz. Yani ikinci sayım belli bir süre sonra yapılmaktadır. Sayıcının yeniden sayım yapabilme durumunu kazanması için gereken süreye ÖLÜ ZAMAN denir.



Radyasyon ölçüm sistemleri

- Sintilasyon dedektörleri (katı, sıvı tipli)
- Elektrona verilen enerji onu ortamdaki yerinden koparmaya yeterli olmadığı zaman uyarılan elektron, tekrar eski haline dönerken görünür ışık yayar
- Sintilasyon fosforlarının yaydığı ışık, foto çoğaltıcı tüpler tarafından toplanarak, voltaj pulsu haline getirilir. Meydana gelen pulsun büyüklüğü radyasyonun enerjisi ile orantılıdır.



Parıldama fosforu

Bu dedektörlerde foto çoğaltıcı tüpü ve kullanılan fosforu değiştirmek suretiyle değişik tipte radyasyonların dedeksiyonu mümkündür.

Exam-style Question- 1

- Activity of a radioactive nuclid is today 10mCi. The half-life of this nuclide is 2 days. Please calculate the activity of this nuclide 8 days before.

Answer:

Today	→ 10 mCi
2 days before	→ 20 mCi
4 days before	→ 40 mCi
6 days before	→ 80 mCi
8 days before	→**160 mCi**

Exam-style Question- 2

- Please match the following radiation terms with their specified units.

1. Radioactivity	A. Sievert
2. Equivalent dose	B. Gray
3. Ion Dose	C. Curie
4. Absorbed Energy Dose	D. Röntgen

Answer: **1C, 2A, 3D, 4B**

Exam-style Question- 3

- Parent nucleus ${}^{A}_{Z}X_{N}$ forms the daughter nucleus Y as a result of β^+ decay. So, which one of the following will be the daughter nucleus Y?

(A=mass number, Z=atomic number (number of protons), N=number of neutrons)

a) ${}^{A}_{Z}Y_{N}$ b) ${}^{A+1}_{Z}Y_{N+1}$ c) ${}^{A-1}_{Z-1}Y_{N}$ d) ${}^{A}_{Z+1}Y_{N-1}$ e) ${}^{A}_{Z-1}Y_{N+1}$

Answer:

$p^+ \rightarrow n + \beta^+$

β+ (a positron) is released and the atomic number decreases by 1 (Z-1).

But neutron number increases by 1 (N+1).

Because the mass number is A=Z+N. Mass number does not change.

So the daughter nucleus is ${}^{A}_{Z-1}Y_{N+1}$

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