DEPARTMENT OF MEDICAL AND
BIOLOGICAL PHYSICS

X-RAY RADIATION. RADIOACTIVITY. DOSIMETRY OF IONIZING RADIATION

Lecture № 9 for for 1st year students of specialty Dentistry

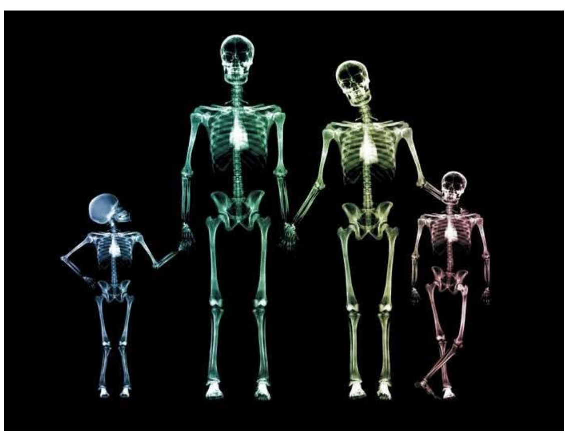
Plan of the lecture

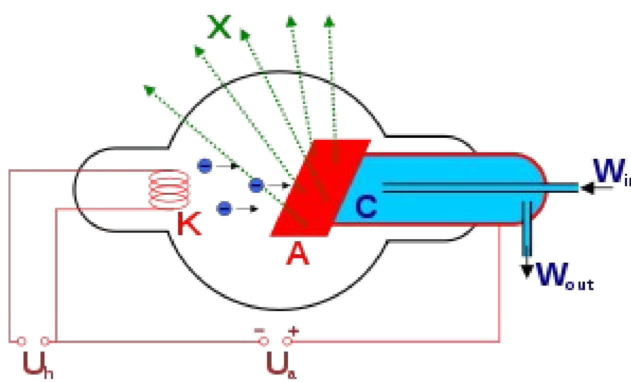
1. 1. X-radiation
2. Bremsstrahlung (Braking) X-radiation. Characteristic X-radiation

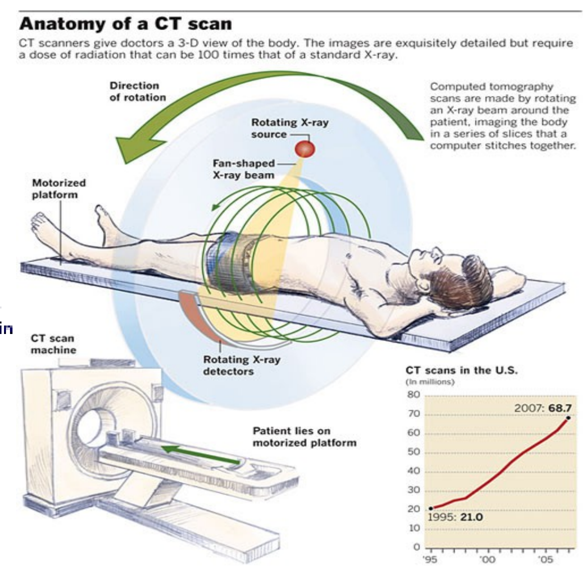
3. Interaction of X-radiation with matter

4. The phenomenon of radioactivity. Types of radioactive decays

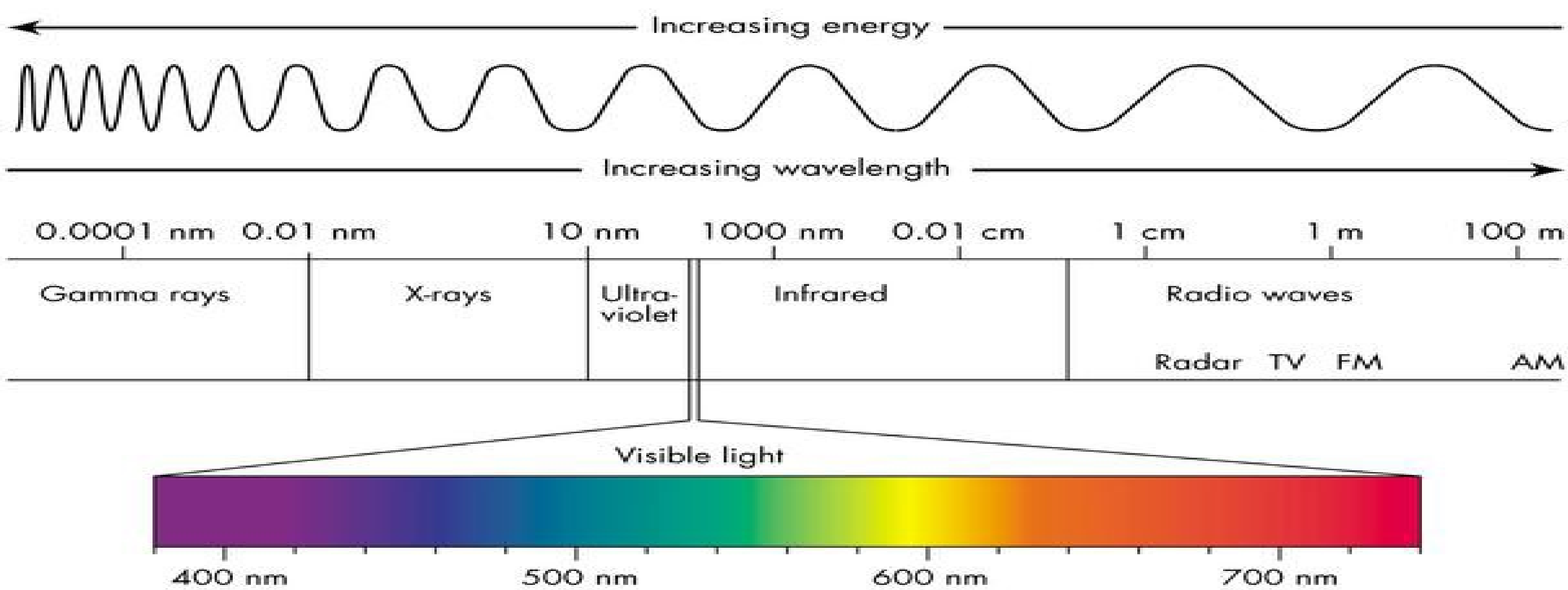
2. The law of radioactive decay
3. The Application radiation in medicine







- ***X-radiation (Röntgen rays)*** is electromagnetic waves with wavelengths ***λ*** from ***10^{-5} nm*** to ***80 nm*** (on the scale of electromagnetic waves it is between gamma-radiation and ultraviolet radiation).



X-ray radiation is classified:

1) <u>On the mechanism of occurrence</u>:

- brake (bremsstrahlung)
- characteristic

2) <u>On wavelength (or on energy):</u>

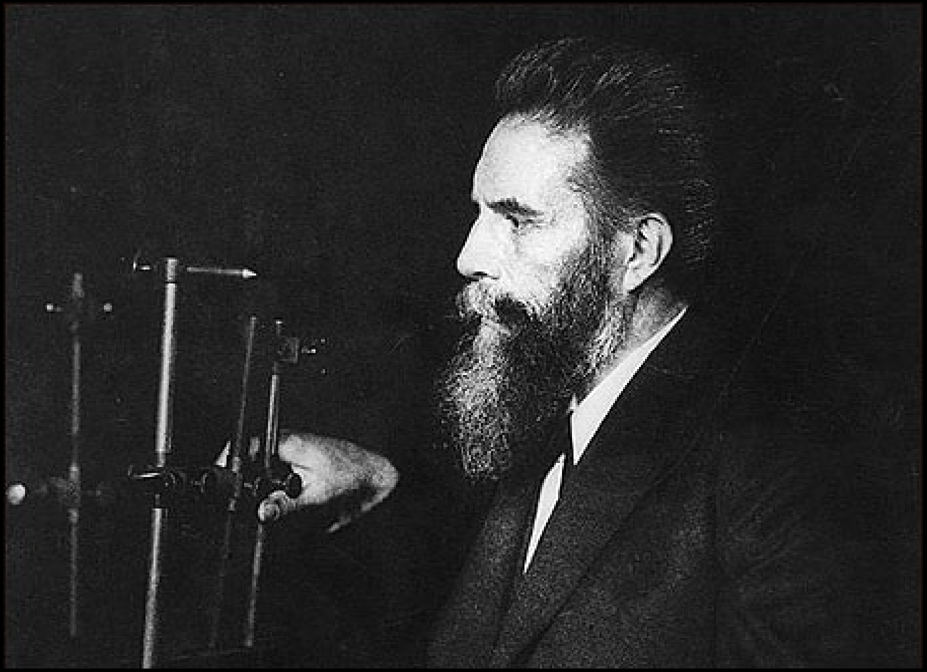
- soft (long-wave)
- hard (short-wave)

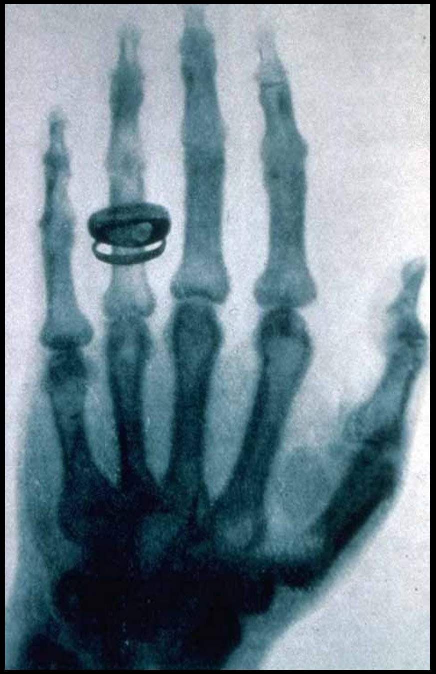
Wilhelm (27 March 1845 – 10 February 1923)

- Outstanding German physicist
- 1895, produced and detected X-rays (Röntgen rays)
- Worn the first Nobel Prize in Physics in 1901.

In honour of his Conrad Röntgen

accomplishments, in 2004 the International Union of Pure and Applied Chemistry (IUPAC) named element 111, a radioactive element with multiple unstable isotopes, roentgenium





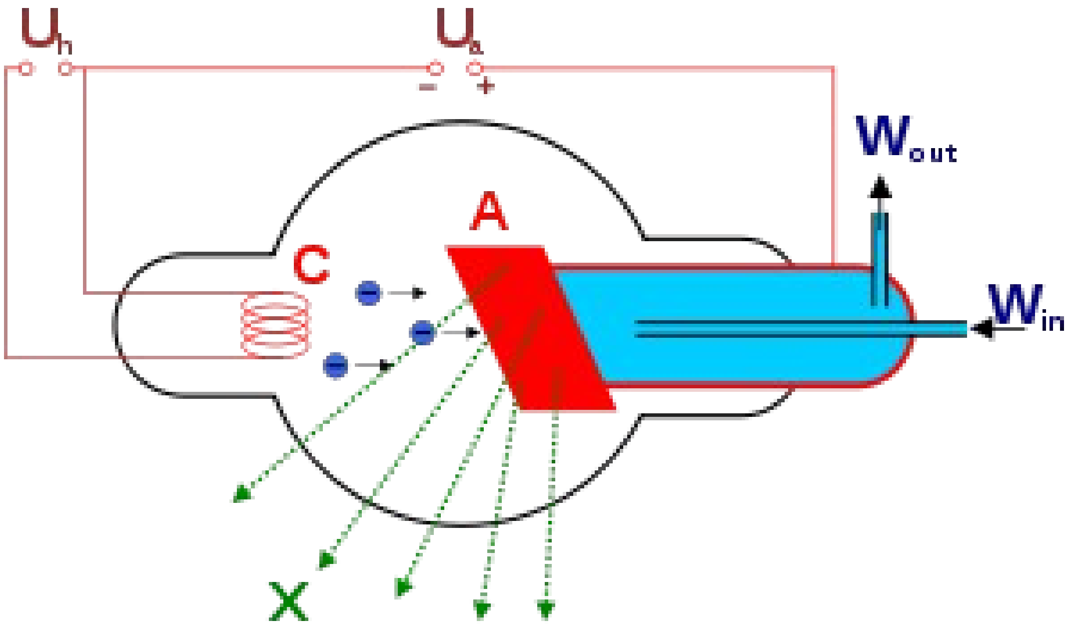
<u>Brake (bremsstrahlung) *X-radiation*</u>

- The source of the brake X-radiation is the ***X-ray tube.***
  <u>X-ray tube is a two-electrode vacuum device.</u>
  It is a glass tube from which air is pumped out. Inside the tube is a vacuum. Tube contains 2 electrodes – cathode (-) and anode (+).

<u>X-ray tube (scheme):</u>

C: cathode/*filament* (-)

A: anode (+)



Principle of operation of X-ray tube

The heated cathode emits electrons.

Under the action of the voltage (U) between cathode and anode the electrons accelerate and bombard the anode's surface.

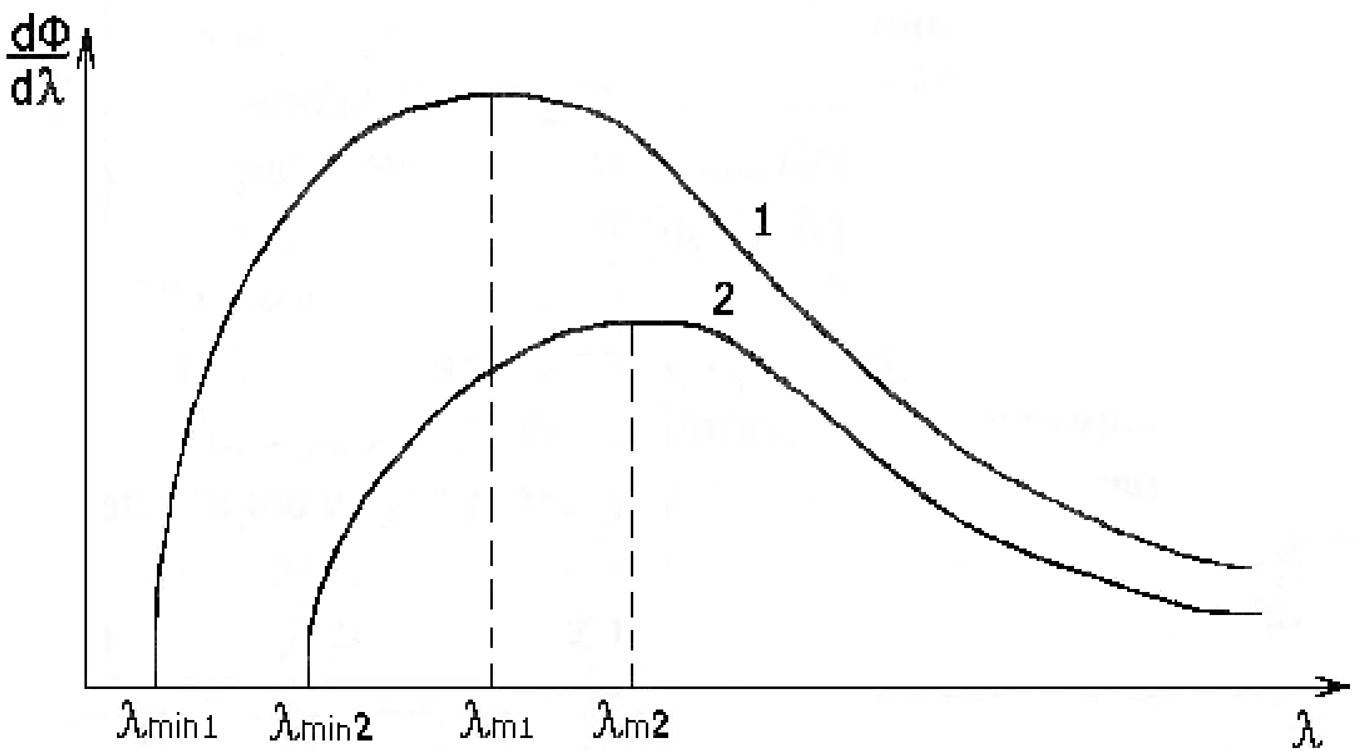
In the material of the anode electrons are decelerated (braked) and Bremsstrahlung X-radiation occurs.

The anode (***anticathode)*** surface is made of ***refractory materials*** with a high atomic number Z.

When the electron is braked in the anode material, only small part ***(2%)*** of its energy is expended on ***exciting X-radiation***. The remaining part is expended on ***anode heating***.

X-ray tube is the main part of the **X-ray apparatus**:

- Since the ratio of these parts is random, the energy of the emitted quantum of X-radiation (h↘) can vary within wide limits. Therefore the ***Spectrum*** of bremsstrahlung X-radiation is ***continuous***.



The energy of the emitted quantum of X-radiation $h\nu$ ($\nu = c/\lambda$) is less than or equal to the energy of the electron (eU) bombarding the anode:

$$h\nu = h\frac{c}{\lambda} \leq eU \qquad \lambda \geq \frac{hc}{eU}$$

The minimal wavelength (λ_{min}) in the X-radiation spectrum is:

$$\lambda_{min} = \frac{hc}{eU} = \frac{1.24}{U}$$

h - Planck's constant ($h=6.626 \cdot 10^{-34}$ J $\cdot$s)

c – light velocity in vacuum ($c=3 \cdot 10^{8}$ m/s)

e - electron charge ($e=1.6 \cdot 10^{-16}$ C)

U – voltage between cathode and anode

Bremsstrahlung ***X-radiation flux*** ***Φ*** (W) :

$$\Phi = kIU^2Z$$

U is voltage (V)

I is current (A)

Z is ***the atomic number*** of the anode material

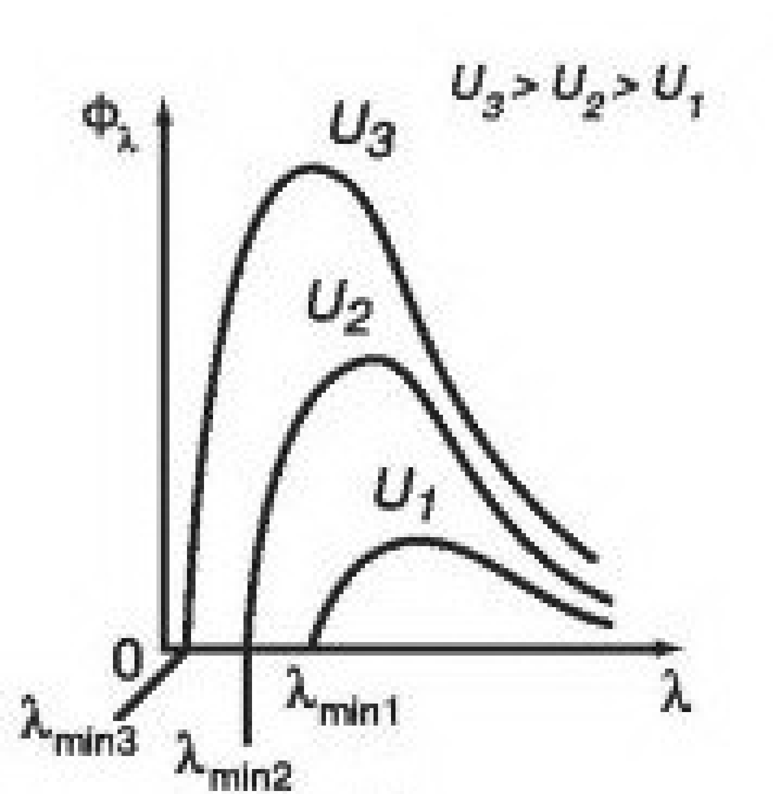
$k=10^{-9}\ W^{-1}$ is the proportionality coefficient

When interacting with a material the ***radiation penetrating capacity*** depends on the radiation quantum energy ($E=\mathbf{hc/\lambda}$).

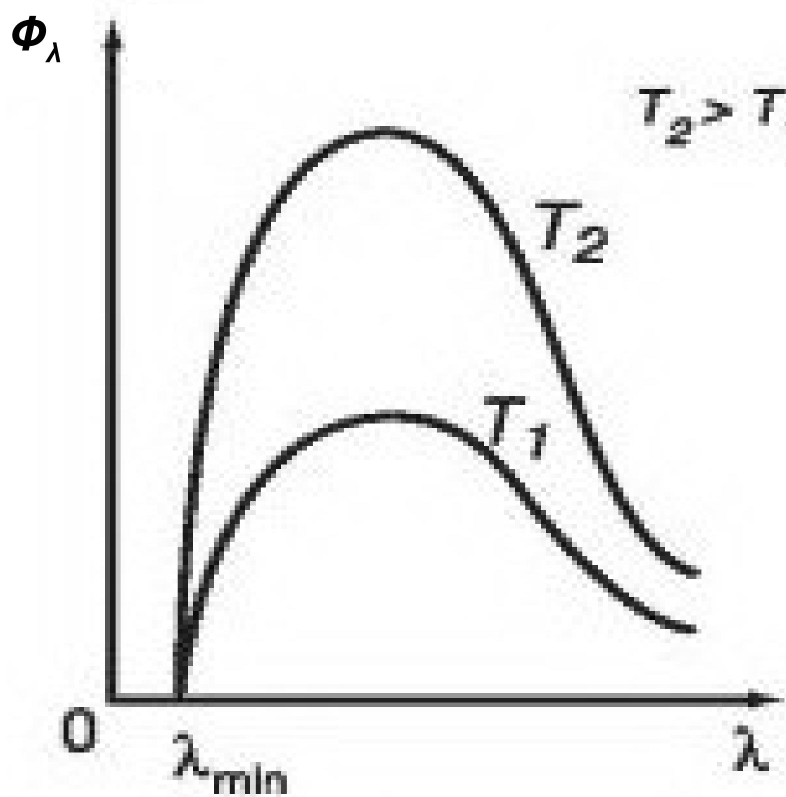
Shortwave radiation has higher quantum energy and penetrates a material deeper. Hence, it is known as "***hard radiation***".

Longwave radiation is less penetrating and it is known as "***soft radiation***".

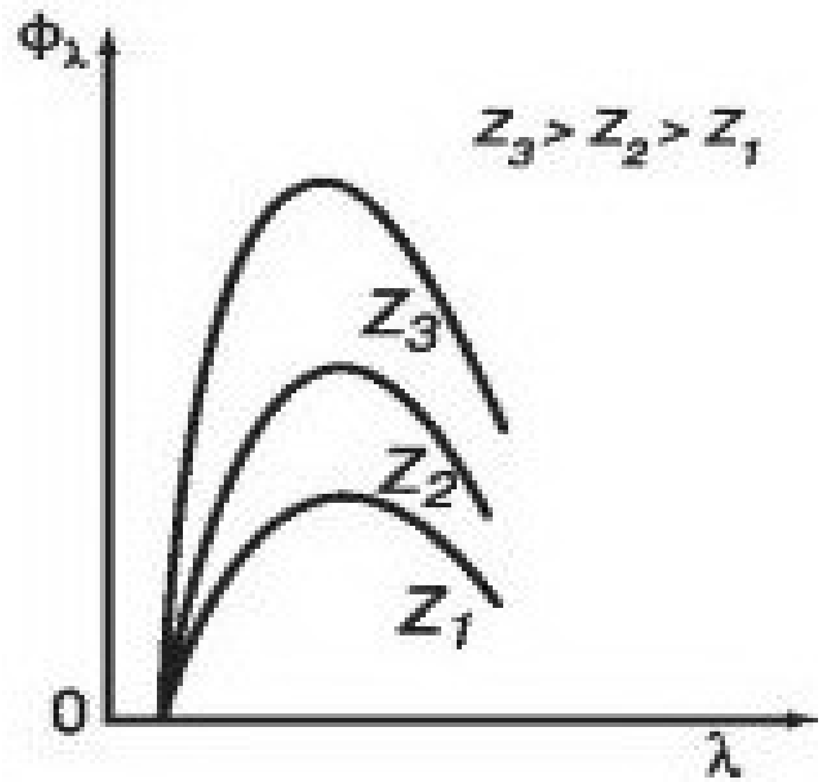
By increasing the anode voltage (U) one can change the spectral composition of radiation and **increase its hardness** (λ_{min} decreases):



If the filament temperature (T) increases: electron emission from the cathode increases and the current (I) in the X-tube circuit increases, the radiation power (Φ) increases in proportion to the anode current, but the spectrum energy distribution remains invariable.



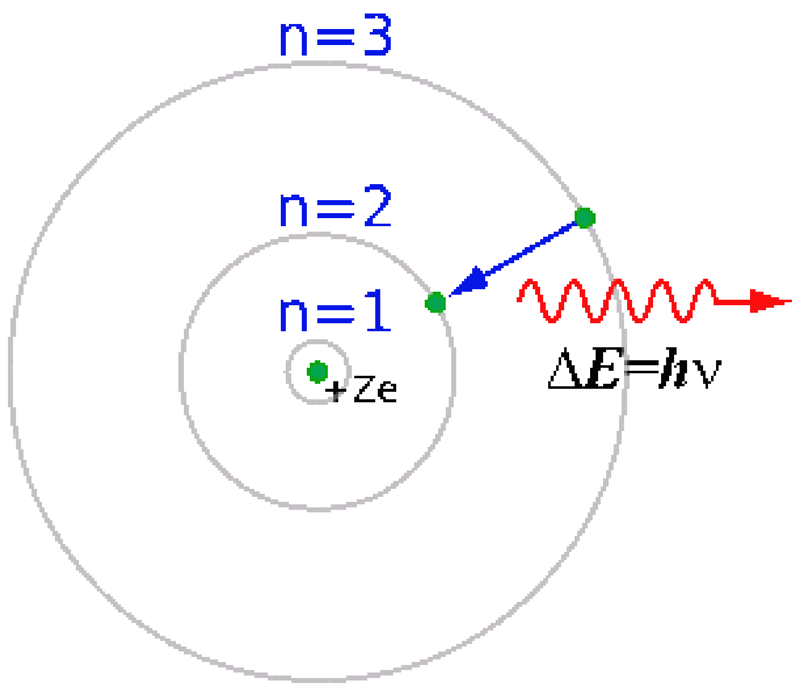
Anticathode mirror (the part of the anticathode bombarded by electrons) is heated to high temperatures and should be made of refractory materials with high value of Z (tungsten and molybdenum).



Characteristic X-radiation

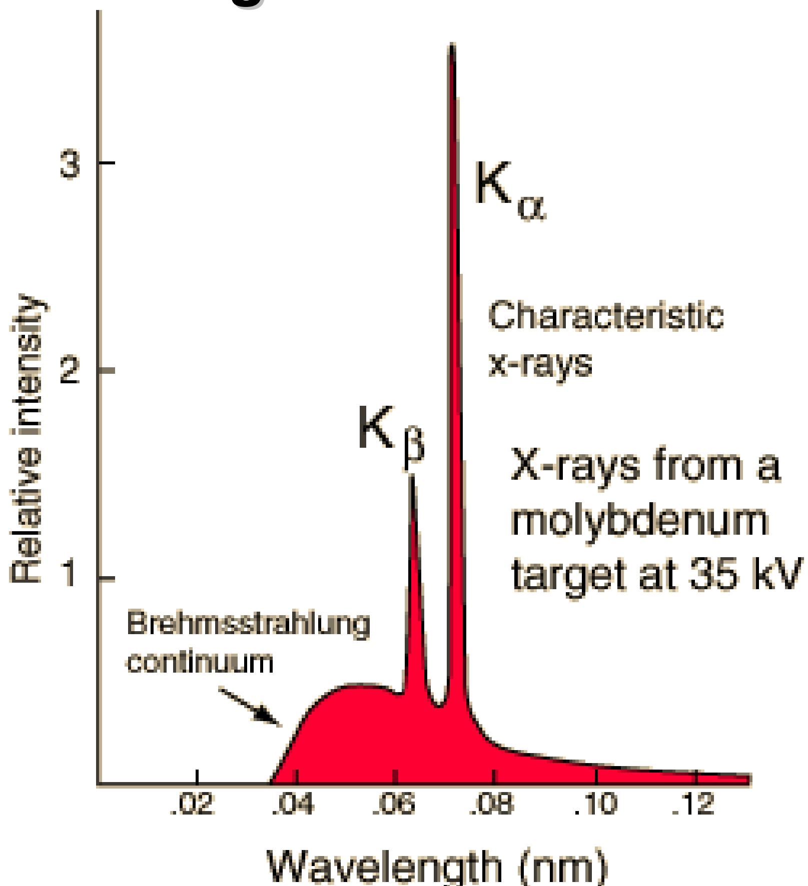
is created by atoms of elements with a high atomic number (Z) when the electron of one of the upper shell levels transits to the one of the lower levels.

During such transitions, the difference of level energies (ΔE) is large and the wavelength of the emerging photon belongs to the X-radiation range.



The X-ray tube can be used not only for obtaining *bremsstrahlung radiation*, but for generating *characteristic radiation* as well.

This occurs when the X-ray tube voltage is increased to make the energy of electrons bombarding the anode sufficient to excite an atom. In this case, *the X-radiation spectrum contains **braking** and **characteristic radiation***.



Since the structure of the lower levels of all heavy atoms is similar, the spectra of characteristic X-radiation of different heavy atoms are also similar.

Characteristic X-radiation spectra are linear and described by the *Moseley law:*

$$\sqrt{\nu} = A(Z - B)$$

ν is the frequency of X-radiation line,

Z is the atomic number,

A and **B** are constants whose values are determined by the values of stationary state numbers n

Interaction of X-radiation with Material

When X-radiation passes through a material, its radiation flux (***Φ***) attenuates according to the ***Bouguer's law :***

$$\Phi = \Phi_0 \cdot e^{-\mu \ell}$$

Φ_0 is the radiation flux incident on the material;

Φ is the radiation flux passed through a material layer and retained its direction of propagation;

l is the thickness of the material layer;

μ is *a linear attenuation factor* for X-radiation.

Three mechanisms of X-radiation interaction with the electron shells of the atoms:

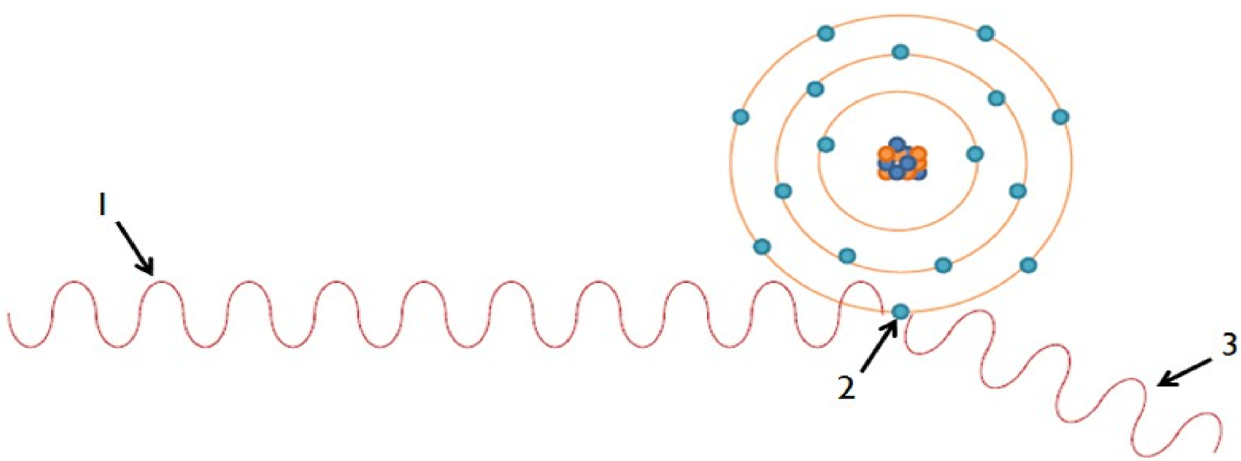
1. ***coherent scattering***
2. ***incoherent scattering***

   (*Compton effect, or Compton scattering*)
3. ***photoeffect***

1. Coherent scattering

- is observed when the X-radiation quantum energy is less than energy of atom ionization (i.e. the energy required for detaching an electron from an atom);
- is characteristic for long-wave X-radiation.
- Direction of propagation of X-radiation changes without radiation energy absorption by the material.

Coherent scattering



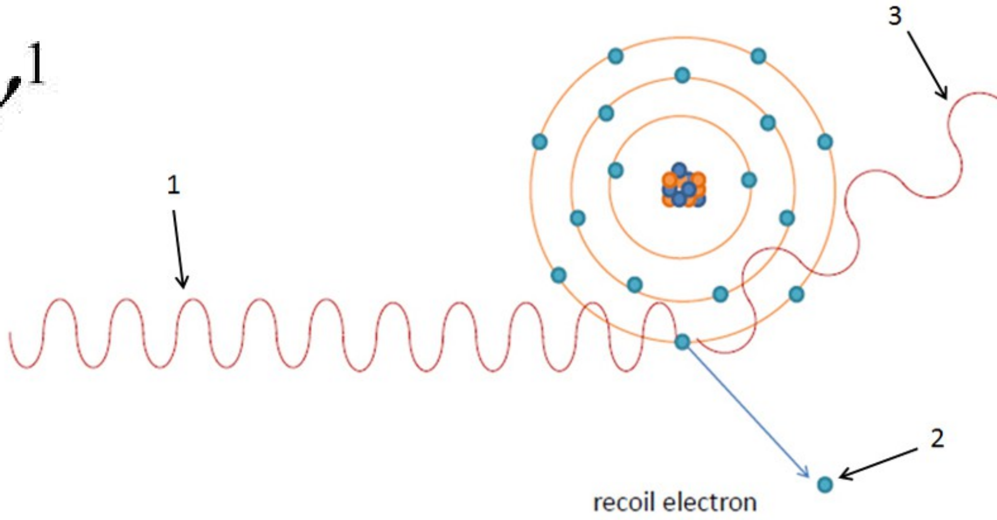
2. ***Incoherent scattering :***

X-radiation quanta interact with the ***outer-shell electrons of an atom***, i.e. with electrons having a weaker binding with the nucleus than the inner-shell electrons do.

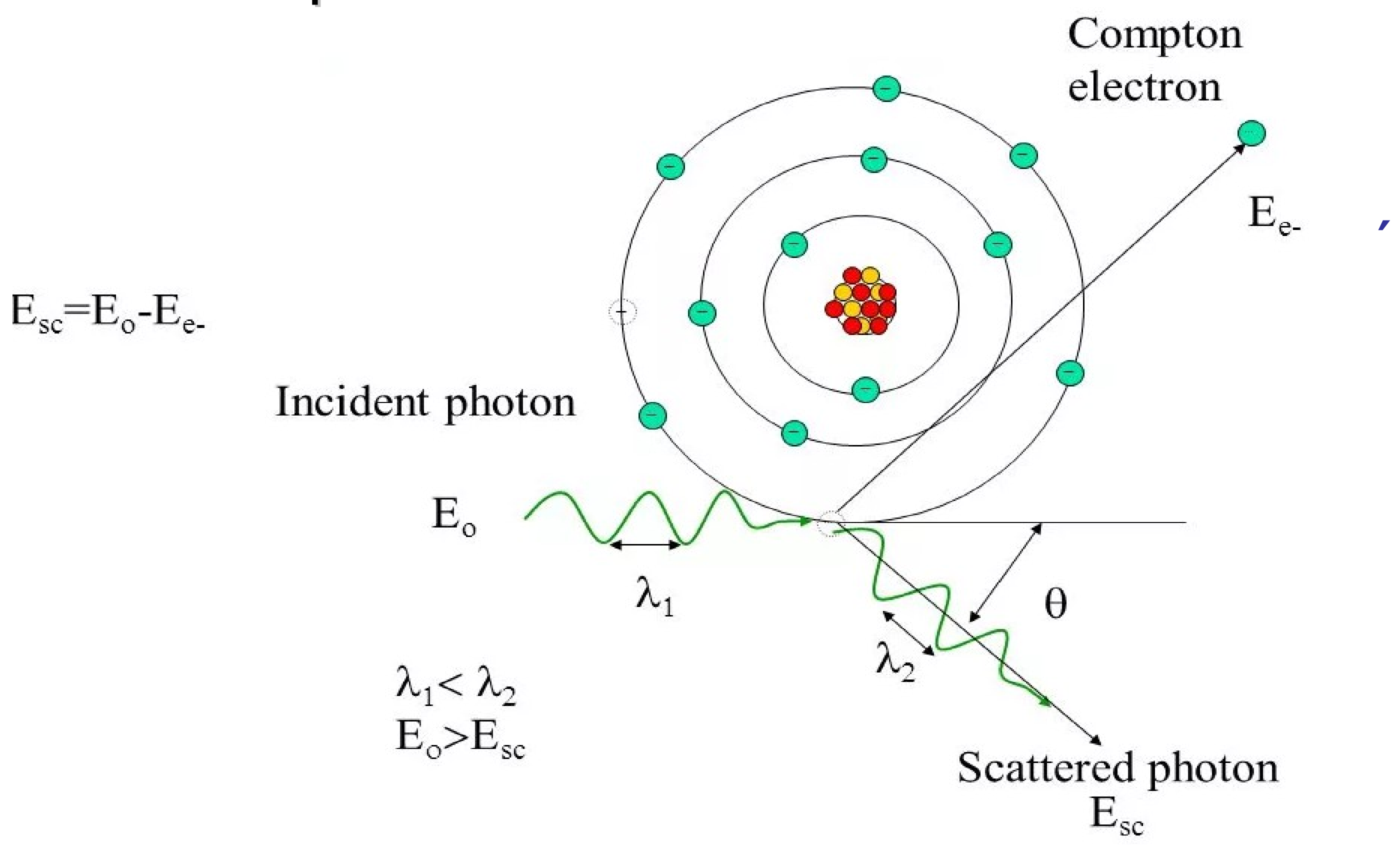
The electron is detached from the atom (the atom is ionized) and acquires kinetic energy.

X-radiation quantum energy is expended on detaching the electron and imparting the kinetic energy.

$$h\nu = A_{в} + \frac{mv^{2}_{1}}{2} + h\nu^{1}$$



- In so doing, a radiation quantum is formed, which has ***a lesser energy*** (with a longer wavelength), and moves in a direction differing from that of the initial quantum, i.e. *radiation dissipation occurs*.
- It is just because the scattered quantum energy differs from that of the initial quantum that such type of scattering is known as ***incoherent***.
- Electrons detached from atoms during the Compton effect are known as Compton electrons.

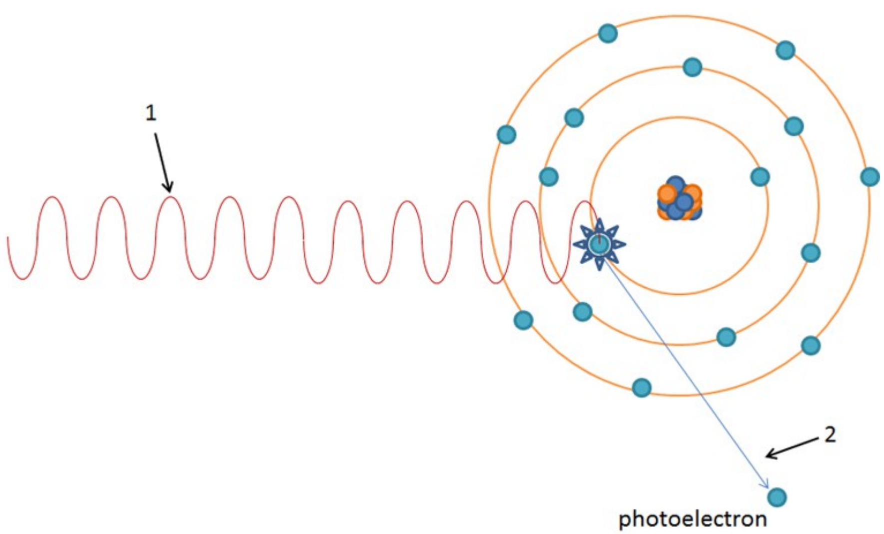


3. Photoeffect

X-radiation quanta interact with the inner-shell electrons of an atom; the electrons being detached from the atom (atom ionization).

- Since the inner-shell electrons have a stronger binding to the nucleus than outer-shell electrons do, the X-radiation quantum expends all its energy on detaching the electron from the atom, i.e. radiation absorption occurs.

Photoelectric effect



All three effects of X-radiation interaction with a material contribute to the total value of the ***Attenuation factor*** (***μ***):

$$\mu = \mu_c + \mu_i + \mu_{ph}$$

$\boldsymbol{\mu_c}$, $\boldsymbol{\mu_i}$ and $\boldsymbol{\mu_{ph}}$ are the components of the ***coherent***, ***incoherent*** and ***photoeffect scattering*** respectively

Attenuation of X-radiation flux by a material is due to the processes of radiation energy *absorption* (τ) and radiation energy *scattering* (σ) :

Absorption coefficient (τ)

Scattering coefficient (σ)

$$\mu = \tau + \sigma$$

The magnitude of absorption coefficient τ is proportional to the material **density (ρ),** the fourth power of element atomic number (Z) and the third power of the radiation wavelength (λ).

$$\tau \sim \rho \cdot Z^4 \cdot \lambda^3$$

Since the linear attenuation factor is proportional to the material density, to characterize X-radiation attenuation by a material, the ***mass attenuation factor*** (μ_m) is used

$$\mu_m = \frac{\mu}{\rho}$$

it does not depend on the absorbing material density

Application of X-radiation in Medicine :

is provided in two ways

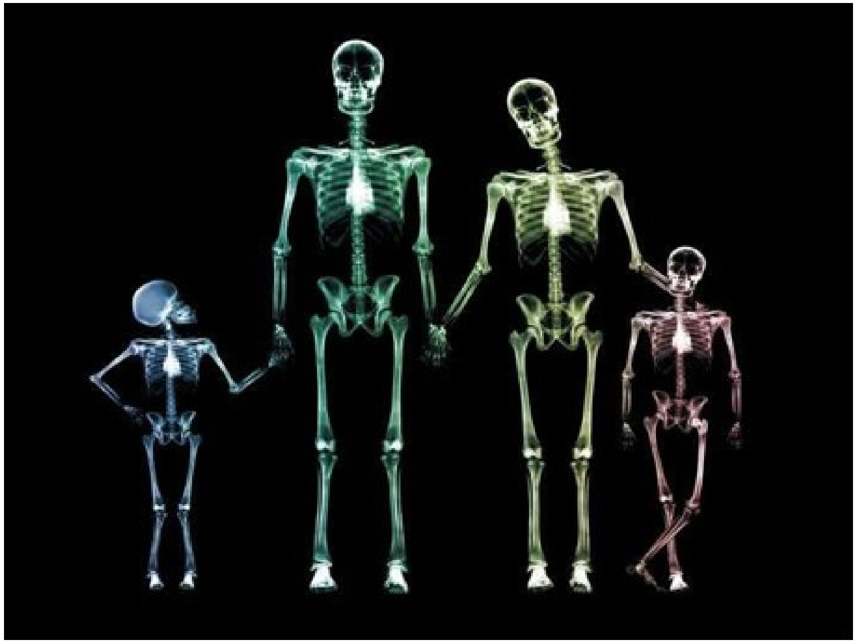
- ***X-ray diagnostics***
- ***X-ray therapy***

X-ray diagnostics is based on the strong dependence of the X-radiation absorption coefficient (τ) of a material on the atomic number (Z) :

$$\tau \sim Z^4$$

(The higher Z, the stronger the absorption.)

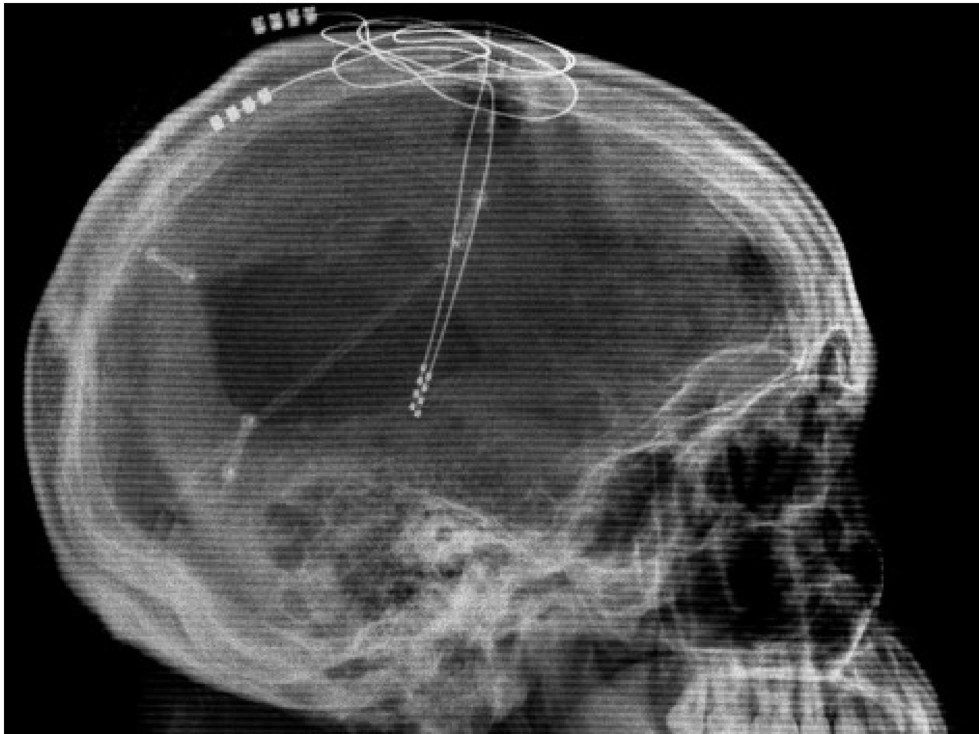
When X-rays pass through a human body, different tissues absorb the radiation in a different manner.



Bone tissue contains **calcium** (Z_{Ca}=20) and **phosphorous** (Z_P=15) atoms;

soft tissues are composed primarily of oxygen (Z_O=8), carbon (Z_C=6) and hydrogen (Z_H=1).

The bones absorb X-radiation dozens of times stronger than the soft tissues.



To register the X-rays that have passed through a human body, either *photo film* or special *luminescent screens* are used.

X-ray diagnostics

(X-ray examining of man’s internal organs):

roentgenoscopy (at luminescent screens),

X-ray filming, or *radiography* (at photo film).

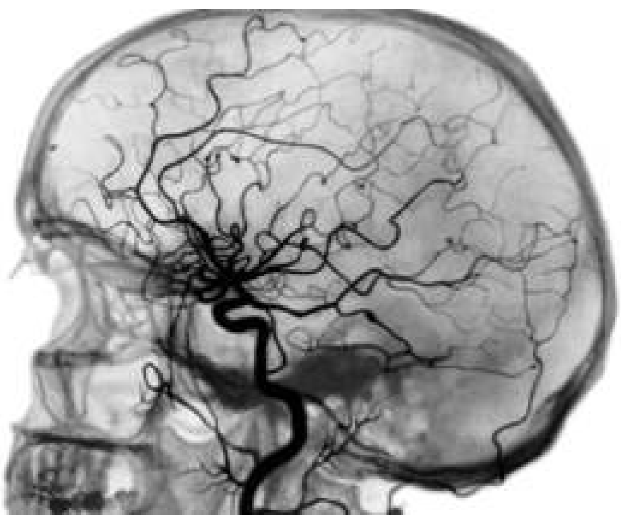
X-ray pictures (roentgenograms) are negatives:

the organs with high density (like bone) on the X-ray roentgenogram are light, with low density (soft tissues) are dark.

Negatoscope (X-ray view box) is a special luminous screen for viewing and descriptions of X-ray roentgenograms.

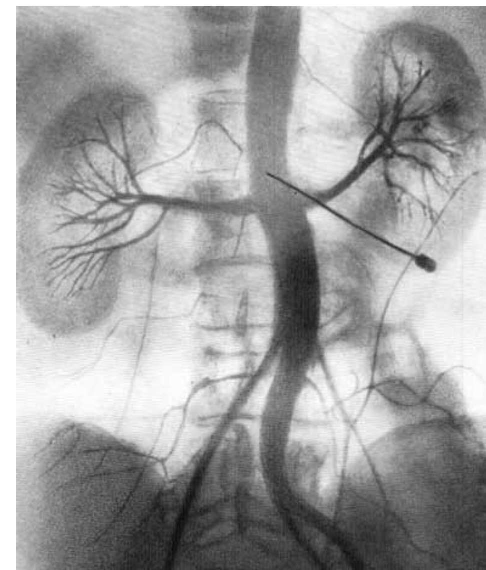
In radiodiagnosis of cavities, blood vessels the radiographic contrast medium (radiopaque substances) well absorbing X-rays can be used (Barium sulphate, iodine-containing substances).

When examining the gastrointestinal tract, the gastric cavity and the intestines are filled with barium sulphate. During X-ray examination of the blood vessels (angiography), substances containing iodine are introduced into the patient’s bloodstream.



Angiography (research after stroke)

Irrigoscopy (X-ray study colon)

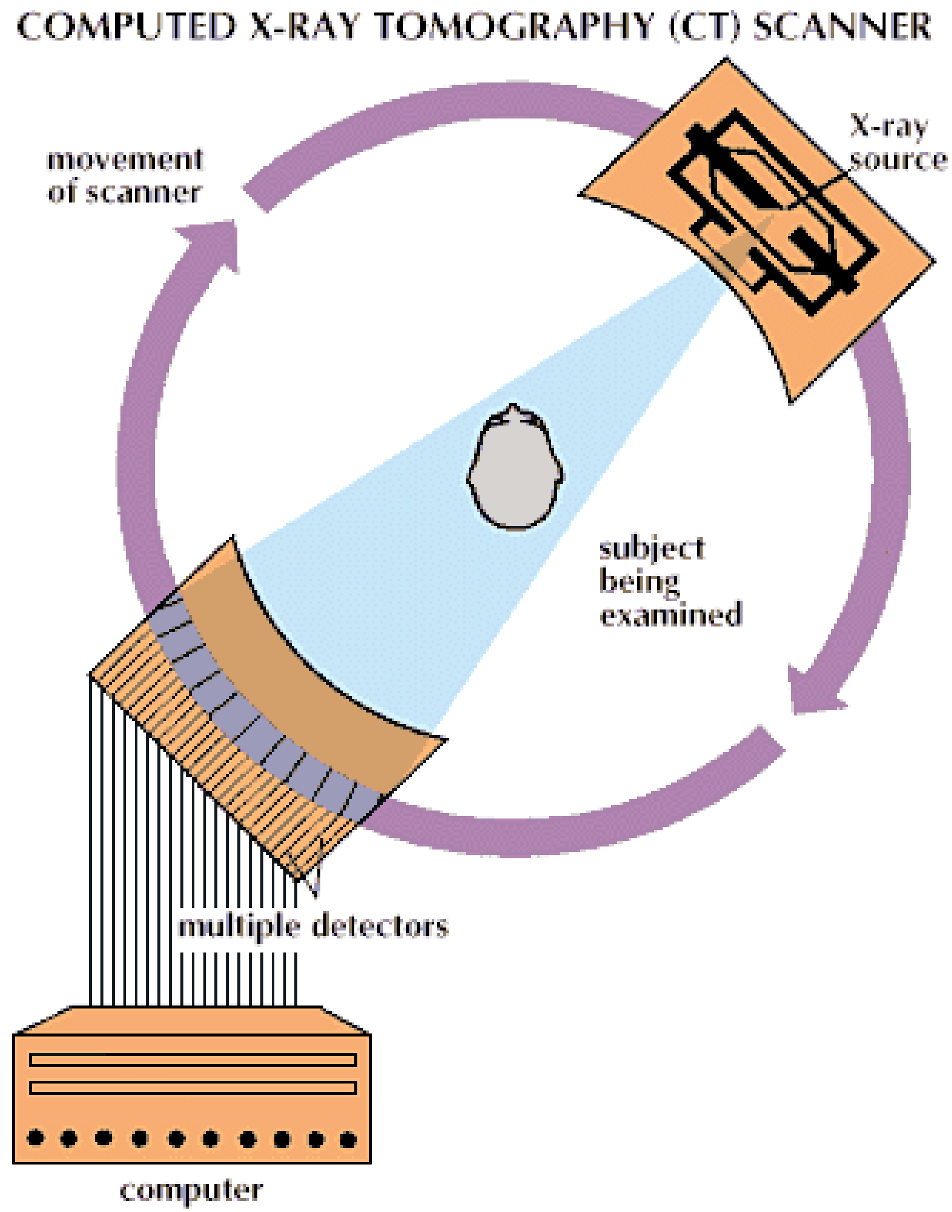


Renal angiography (translyumbalny method)

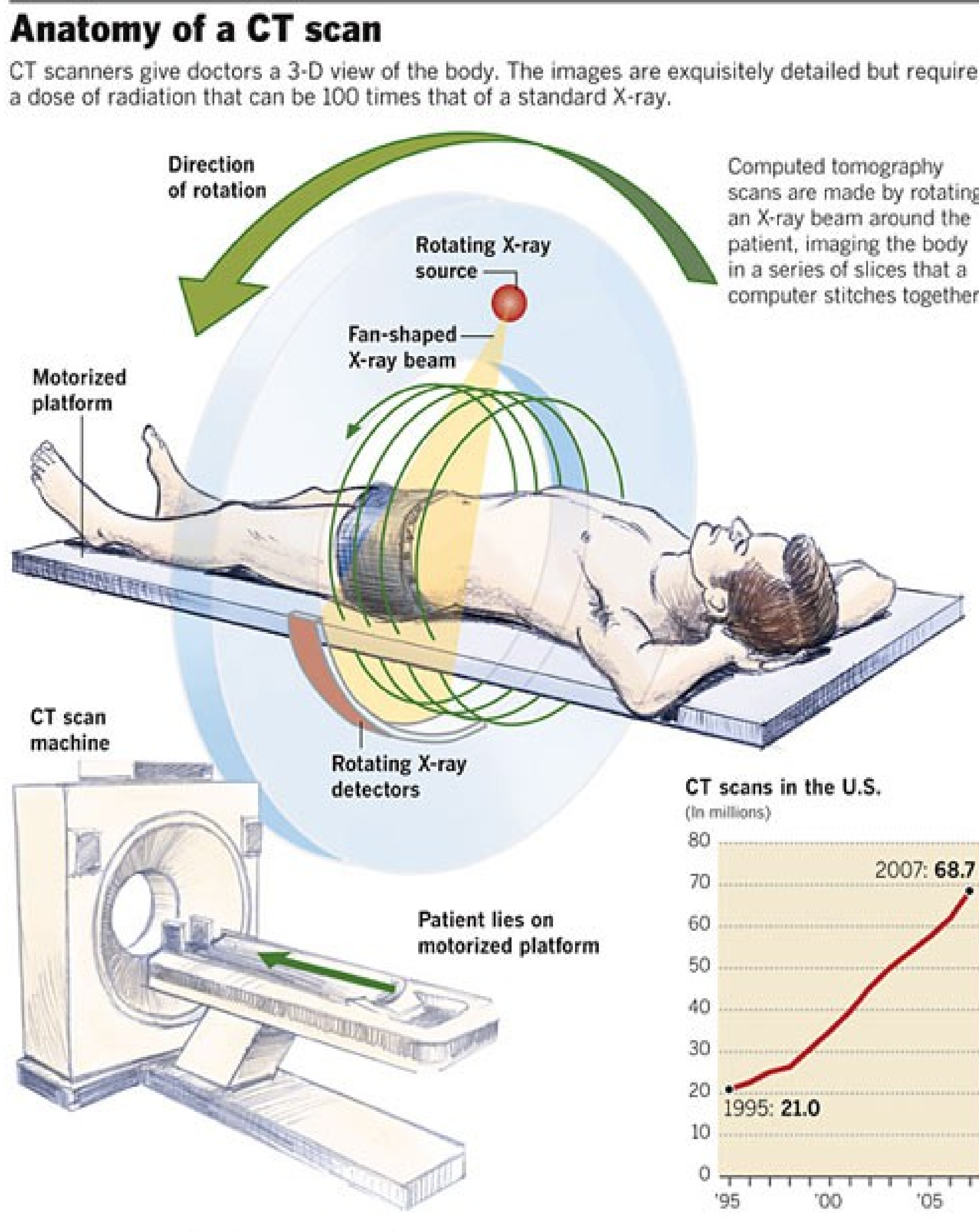
- X-rays have an adverse (or harmful) effect on alive tissue.
- Therefore, to reduce this effect, techniques employing weak radiation fluxes have been developed.
- For example, electron-optical converters

- The technique of ***computed X-ray tomography*** **(CT) scanner** has the largest information content, but technically, it is the most complicated one.

- A thin X-ray is radiated through a thin flat area of the human body (layer), and the value of the flux that has passed is registered.



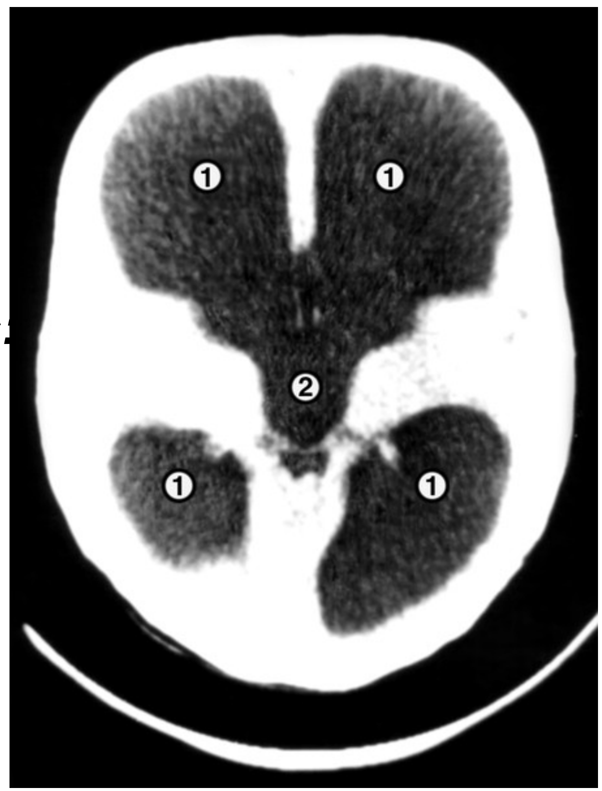
- By X-irradiation of the different areas in the layer in different directions it is possible, at a sufficiently large number of measurements, to calculate the radiation absorption value for each small area (cell) of the layer being examined.



If the calculation results are displayed on a screen as a 2D image, where the layer areas differing for the radiation absorbed are different as to image brightness or color on the screen, a visual presentation of the internal structure of the selected layer of the body is obtained.

CT-method provides the highest information content when identifying ***malignant tumors.***

The resolving power of advanced CT-scanners allows detecting tumors as small as several ***millimeters*** in size.



CT head infant with hydrocephalus: slices, performed on different levels, seen a sharp lateral extension (1) and the third (2) of the ventricles.

CT patient. Cystic formation of the right kidney (after contrast)

The affect of X-rays on tissues for treatment purposes is known as ***X-ray therapy***, which is a special case of ***radiation therapy***.

To implement different techniques involving X-radiation, X-ray units generating radiation of required intensity and hardness are used.

Ionizing radiation

Ionizing radiation (IR) is radiation whose effect on a material causes ionization of the atoms of this material.

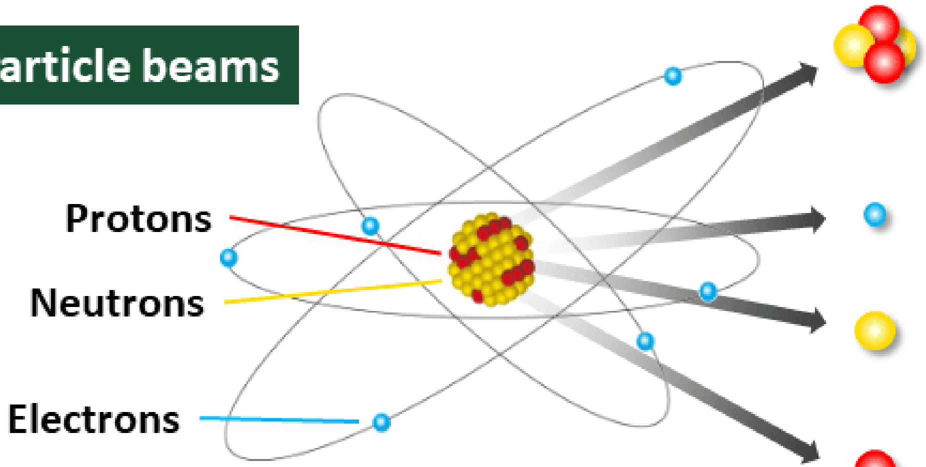
Ionization is a process of transforming the neutral atom into ions – positive (cations) and negative (anions).

In medicine ***X-radiation*** is used the most often.

Radiation — Types of Ionizing Radiation

Ionizing radiation — Radiation that causes ionization

Particle beams



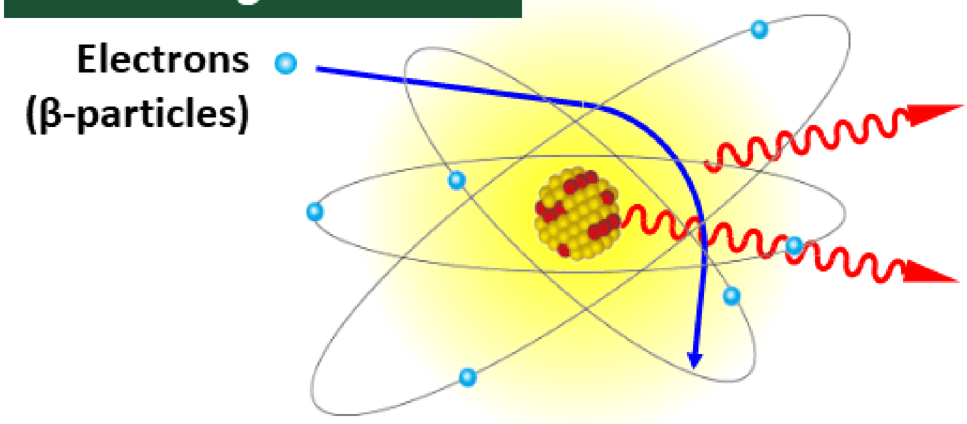
α-particles (helium nuclei ejected from a nucleus)

β-particles (electrons ejected from a nucleus)

Neutron beams (produced in nuclear reactors, accelerators, etc.)

Proton beams (produced in accelerators, etc.)

Electromagnetic waves



X-rays (generated outside a nucleus)

* X-rays generated when electrons within an atom are caused to travel between orbits by incident electrons are called characteristic X-rays.

γ-rays (emitted from a nucleus)

Radioactivity

Ionizing radiation, except for X-radiation, occurs most often during ***radioactive decay*** of atom nuclei – due to the phenomenon of ***radioactivity***.

Radioactivity is a spontaneous decay of unstable nuclei followed by emission of other nuclei or elementary particles.

1898, ***Pierre*** and ***Marie Curie*** studying the radioactivity, discover 2 radioactive elements - **radium** and **polonium**.

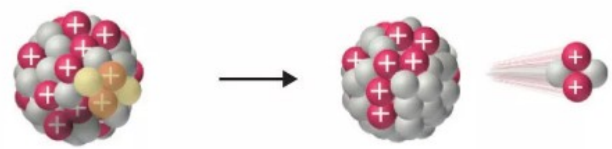
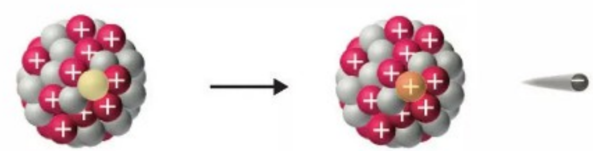
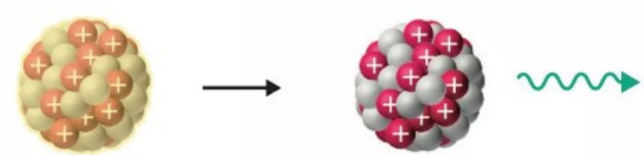
1903, ***Marie, Pierre Curie*** and ***Henri Becquerel*** won the *Nobel Prize* for physics - for the joint discovery of radioactivity.

She became the first female lecturer at the Sorbonne, and in 1908 she was appointed professor.

1911, ***Marie Curie*** won the *second Nobel Prize* for chemistry - for the isolation of pure radium.

Basic types of radioactive decay of nuclei:

1. α-decay
2. β-decay:
   - *electron decay* (β^--decay)
   - *positron decay* (β^+-decay)
   - *e-capture*

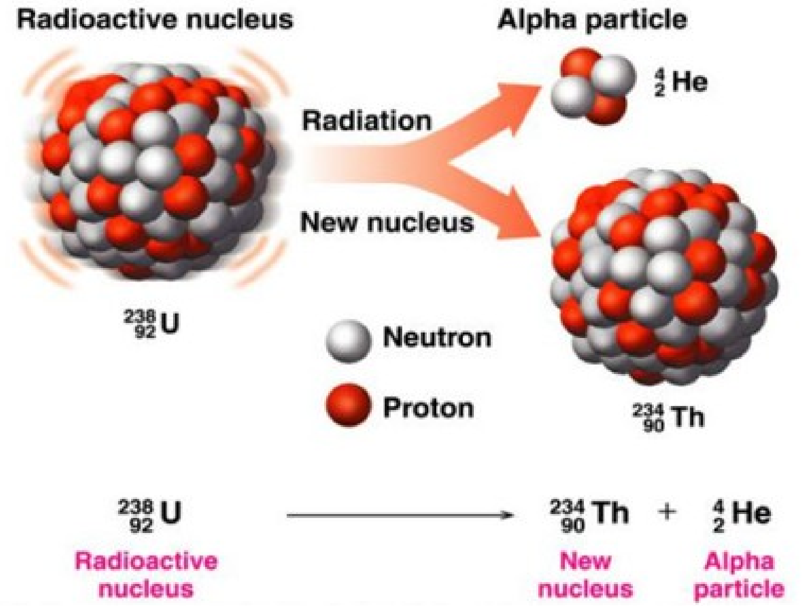
Decay Type	Radiation Emitted	Generic Equation	Model
Alpha decay	${}^{4}_{2}\alpha$	${}^{A}_{Z}\mathrm{X} \longrightarrow {}^{A-4}_{Z-2}\mathrm{X'} + {}^{4}_{2}\alpha$	 Parent, Daughter, Alpha Particle
Beta decay	${}^{0}_{-1}\beta$	${}^{A}_{Z}\mathrm{X} \longrightarrow {}^{A}_{Z+1}\mathrm{X'} + {}^{0}_{-1}\beta$	 Parent, Daughter, Beta Particle
Gamma emission	${}^{0}_{0}\gamma$	${}^{A}_{Z}\mathrm{X}^{*} \xrightarrow{\text{Relaxation}} {}^{A}_{Z}\mathrm{X'} + {}^{0}_{0}\gamma$	 Parent (excited nuclear state), Daughter, Gamma ray

At ***α-decay*** an α-particle is emitted.

α-particle is a helium atom nucleus $^{4}_{2}\mathrm{He}$:

mass number (A = 4)

atomic (proton) number (Z = 2)



The α-decay equation has the form:

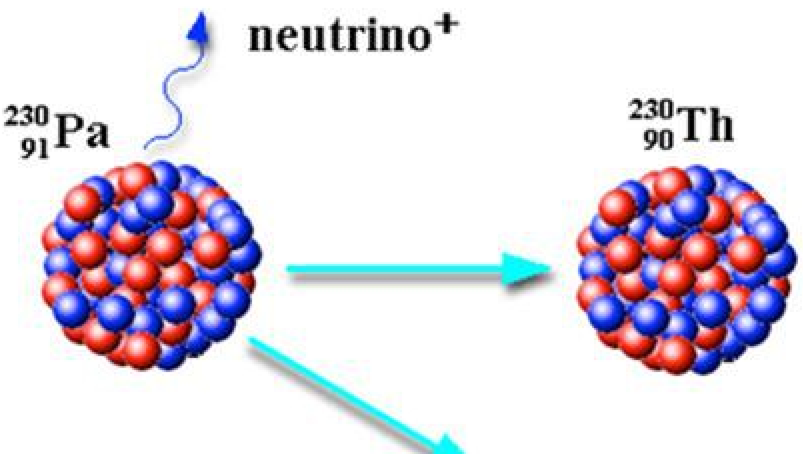
$$^{A}_{Z}X \rightarrow ^{A-4}_{Z-2}Y + ^{4}_{2}\alpha$$

Y (daughter nucleus) is the nucleus formed at α-decay of X nucleus (mother nucleus).

During α-decay γ-radiation also occurs.

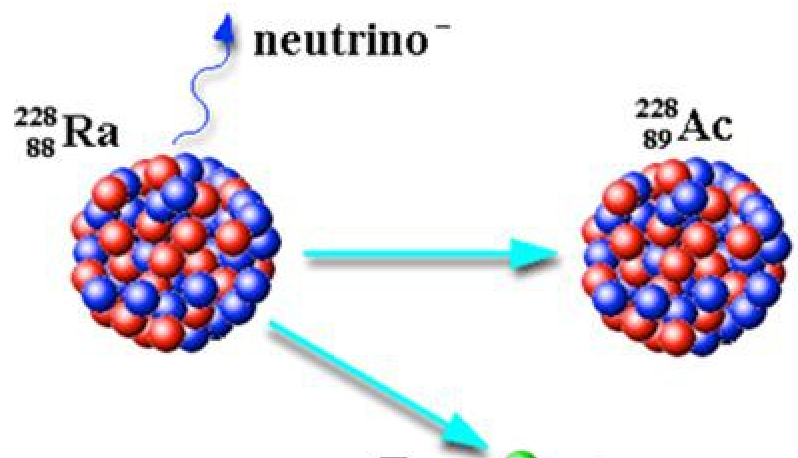
2. Three types of <u>β*-decay*</u>:

- *ELECTRON decay* (β^--decay)
- *POSITRON decay* (β^+-decay)
- *e-CAPTURE*



$^{1}_{1}p \rightarrow {}^{1}_{0}n + {}^{0}_{+1}e + \nu$

$^{230}_{91}Pa \rightarrow {}^{230}_{90}U + {}^{0}_{+1}e + \nu$



$^{1}_{0}n \rightarrow {}^{1}_{1}p + {}^{0}_{-1}e + \bar{\nu}$

$^{228}_{88}Ra \rightarrow {}^{228}_{89}U + {}^{0}_{-1}e + \bar{\nu}$

1) During the ***electron decay*** a β^--particle is emitted, i.e. a fast moving electron.

A new nucleus is formed, with a atomic number a unit greater than that of the mother nucleus.

An antineutrino (ũ) is emitted

β^--decay equation:

$$^{A}_{Z}X \rightarrow ^{A}_{Z+1}Y + ^{0}_{-1}\beta + \tilde{\nu}$$

During the β^--decay an electron is created due to intranuclear transformation of the neutron (n) into the photon (p):

$$^{1}_{0}n \rightarrow ^{1}_{1}p + ^{0}_{-1}\beta + \bar{\nu}$$

2) During ***positron decay***, a β^+-particle is emitted, i.e. a positron (or antielectron).

A new nucleus is formed with a serial number a unity less than that of the mother nucleus. The previous mass number is retained.

A neutrino (υ) is emitted.

β^+-decay equation :

$$^{A}_{Z}X \rightarrow {}^{A}_{Z-1}Y + {}^{0}_{1}\beta + \nu$$

- During the β^+-decay a positron is created due to intranuclear transformation of the proton (p) into the neutron (n):

$$^{1}_{+1}p \rightarrow {}^{1}_{0}n + {}^{0}_{+1}\beta + \nu$$

3) During ***e-capture*** the atom nucleus captures one of the inner electrons of this atom.

In the result the proton transforms into the neutron.

$$ {}_{+1}^{1}p + {}_{-1}^{0}\beta \rightarrow {}_{0}^{1}n + \nu $$

A new nucleus is formed, with a atomic number a unit less than that of the mother nucleus. The previous mass number is retained and a neutrino is emitted.

The e-capture equation:

$$ {}_{Z}^{A}X + {}_{-1}^{0}\beta \rightarrow {}_{Z-1}^{A}Y + \nu $$

At all kinds of β-decay there may occur X-radiation or γ-radiation.

Law of radioactive decay:

During the radioactive decay the number (**N**) of material non-decayed atoms decreases with time (**t**).

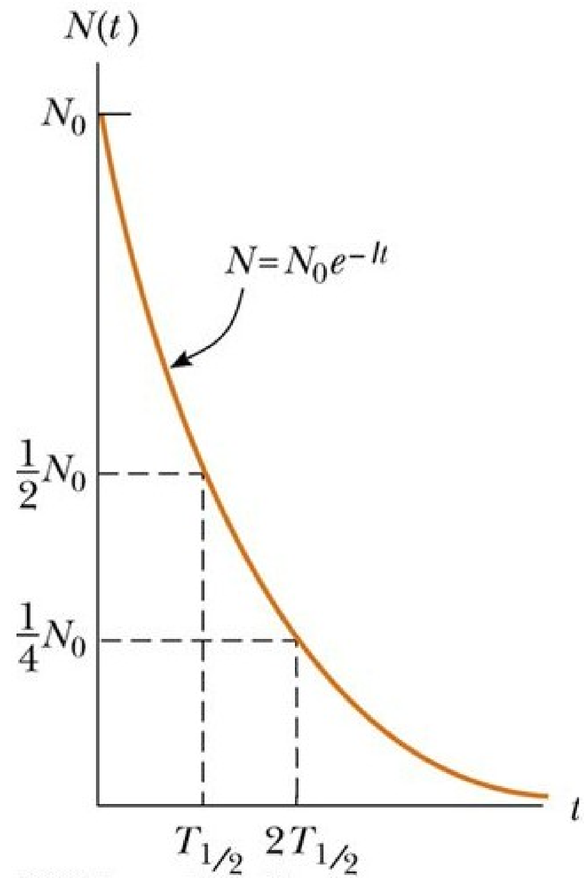
Decay Curve

- **The decay curve follows the equation**

$$N = N_o\, e^{-\lambda t}$$

- **Another useful parameter is the half-life defined as the time it takes for half of any given number of radioactive nuclei to decay**

$$T_{1/2} = \frac{\ln 2}{\lambda} = \frac{0.693}{\lambda}$$



Activity of a radioactive material

characterizes the rate of decay of a radioactive material (**A** is proportional to number of atoms decayed per unit time):

Activity = number of disintegrations per second is equal to the number of atoms present at time *t*, *N(t)* multiplied by the probability of decay per unit time, λ.

$$A(t) = -\frac{dN(t)}{dt} = \lambda N(t)$$

The (mean) lifetime for the decay is $\tau = 1/\lambda$

If $N_1(0)$ is the number at atoms of type N_1 present at time $t=0$ (start of decay counting time), then we can rearrange the equation above to give:

$$dN_1 = -\lambda_1 N_1 dt$$

Integrating both sides and remembering that at time $t=0$, $N_1(t=0)$ we get,

$$N_1(t) = N_1(0)e^{-\lambda t}$$

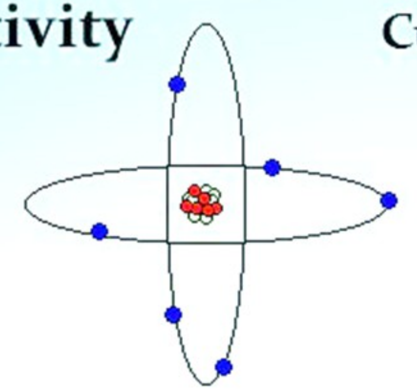
Since the activity at time *t*, *A(t)* is given by:
$A_1(t) = \lambda N_1(t)$, then it follows that

$$A_1(t) = N_1(t=0)\, e^{-\lambda t}$$

System unit of the material activity is ***becquerel (Bq).***

Activity of material equals 1 Bq, if 1 atom of material decays per a second.

- **Activity**



Curie (or Becquerel in SI units)

1 Becquerel (Bq) = 1 dis./sec

1 curie (Ci) = 3.7×10^{10} dis./sec

1 curie (Ci) = 2.22×10^{12} dis./min

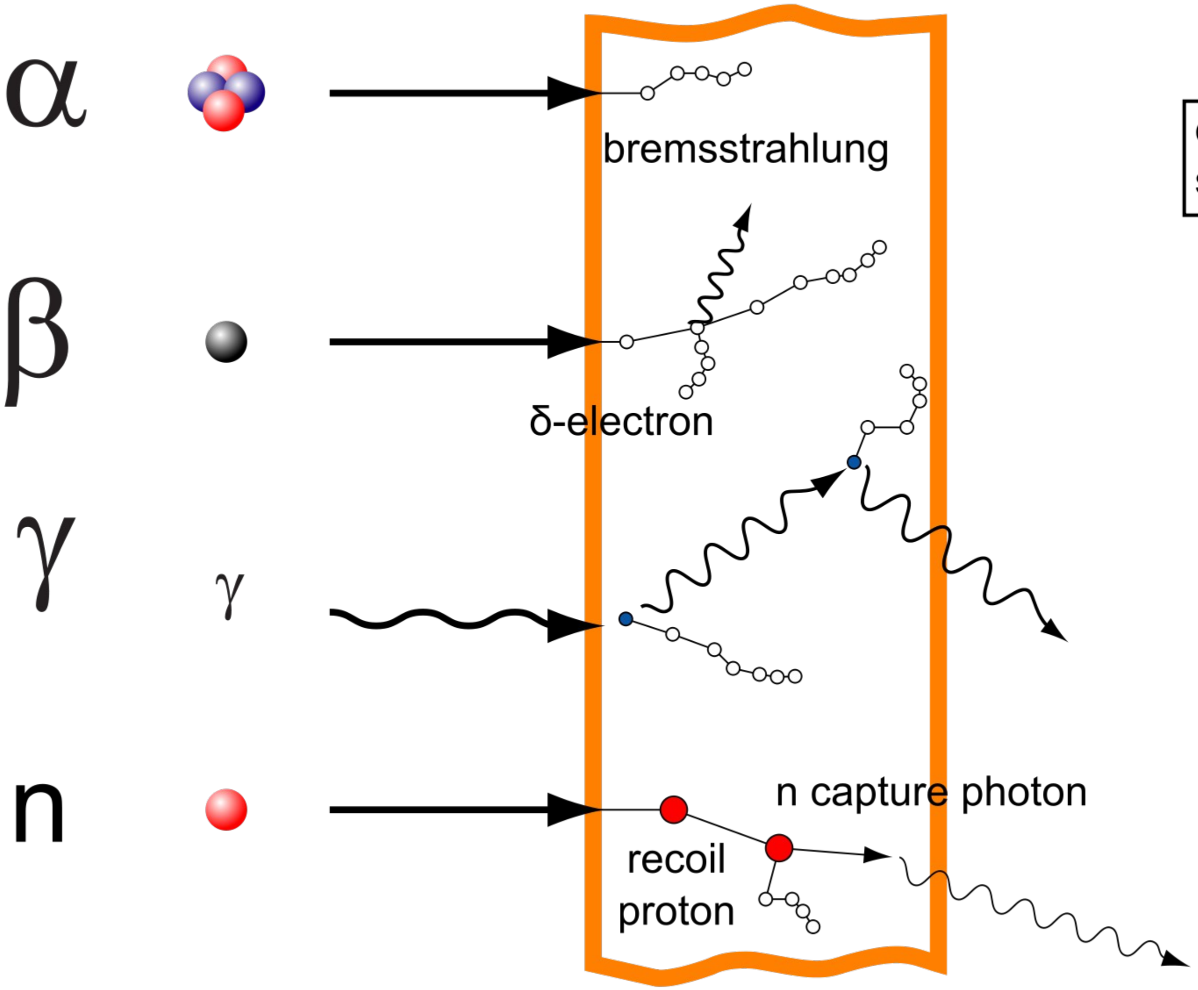
1 mCi = 37 MBq

A "Curie" is a unit of measurement which quantifies the amount of radioactivity present as a disintegration rate. One Curie (Ci) is referenced as the amount of radioactivity present in 1 gram of radium and is equivalent to 3.7×10^{10} disintegrations per second (DPS).

Henri Becquerel

Marie Curie

Interaction of ionizing radiation with matter



charged particles interact strongly and ionize directly

neutral particles interact less, ionize indirectly and penetrate farther

Biophysical basis of the action of ionizing radiation

The effect of radioactive radiation on biological systems is associated with the ionization of molecules. The process of interaction of radiation with cells can be divided into three consecutive stages

1. ***The physical stage*** consists in the transfer of radiation energy to the molecules of the biological system, as a result of which their ionization and excitation occur. The duration of this stage is 10^{-16}-10^{-13} s.

2. ***The physico-chemical*** stage consists of various reactions that lead to the redistribution of excess energy of excited molecules and ions. As a result, highly activeproducts appear: radicals and new ions with a wide range of chemical properties.The duration of this stage is 10^{-13}-10^{-10} s.

3. ***The chemical stage*** is the interaction of radicals and ions with each other and with surrounding molecules. at this stage, structural damage of various types is formed, leading to changes in biological properties: the structure and functions of membranes are disrupted; lesions occur in dna and rna molecules.The duration of the chemical stage is 10^{-6}-10^{-3} s.

4. ***The biological stage***. At this stage, damage to molecules and subcellular structures leads to a variety of functional disorders, to premature cell death as a result of the mechanisms of apoptosis or due to necrosis.

Damage received at the biological stage can be inherited.

The duration of the biological stage is from a few minutes to tens of years.

Note the general laws of the biological stage:

* large disturbances with low absorbed energy (a lethal dose of radiation for a person causes the body to heat up by only 0.001°C);

* action on subsequent generations through the hereditary apparatus of the cell;

* a latent, latent period is characteristic;• different parts of cells have different sensitivity to radiation;

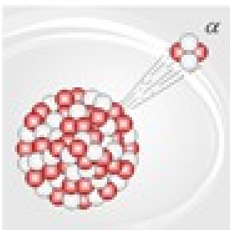
* first of all, dividing cells are affected, which is especially dangerous for the child's body;

* harmful effect on the tissues of the adult body, in which there is division;

* similarity of radiation changes with the processes of pathology of early aging.

Dosimetry and radiation protection

Radioactive decay

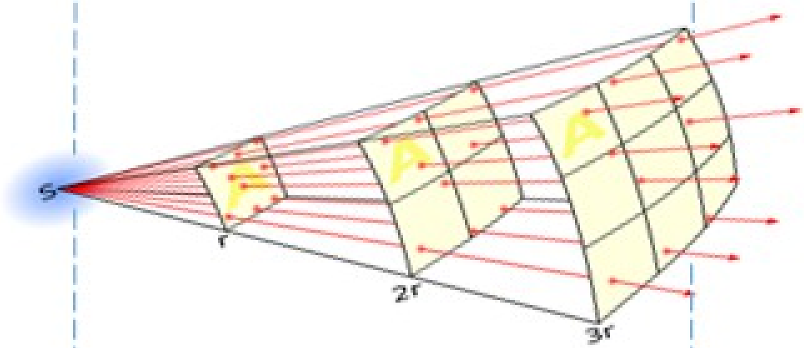


Measurement quantity

- becquerel (Bq)

The becquerel is the SI unit of activity.
1 becquerel = 1 decay per second

Ionizing radiation



Transmission factors

- Distance (Inverse square law)
- Scattering
- Absorption

Ionizing radiation strength from a point source decreases with the square of distance it travels.
The intervening medium can also absorb and scatter radiation.

Detection

Measurement quantities

Dose

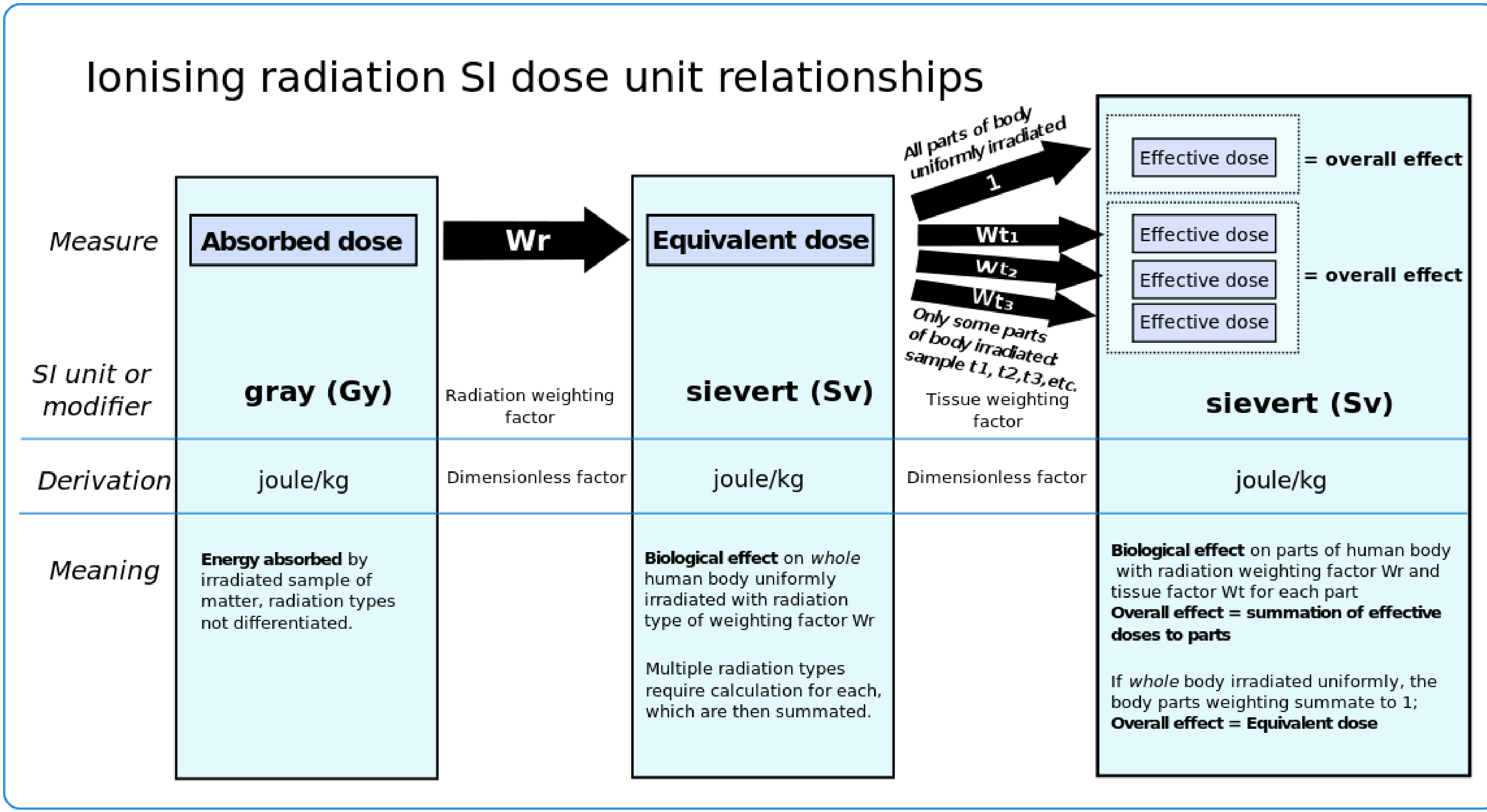
- gray (Gy)
- sievert (Sv)

Particle counts

- per second (cps)
- per minute (cpm)

Both dose and counts are used: depending on the application and the radiation type.
Physical dose is measured in grays, and biological dose in sieverts.

Dosimetry and radiation protection



Dosimetry and radiation protection

Absorbed Dose Grays Gy

Energy Absorbed Joules J

$$D = \frac{E}{m}$$

mass kg

Dose equivalent Sieverts Sv

Absorbed Dose Grays Gy

Radiation weighting factor

$$H = D \times \boldsymbol{K}$$

The Absorbed Dose measures the amount of energy absorbed per kilogram of tissue.

The Equivalent Dose takes into consideration the type of radiation.

$$\dot{H} = \frac{H}{t}$$

Equivalent dose rate.

The same Equivalent Dose always gives the same BIOLOGICAL Effect.

Annual dose equivalent received each year is 2mSv

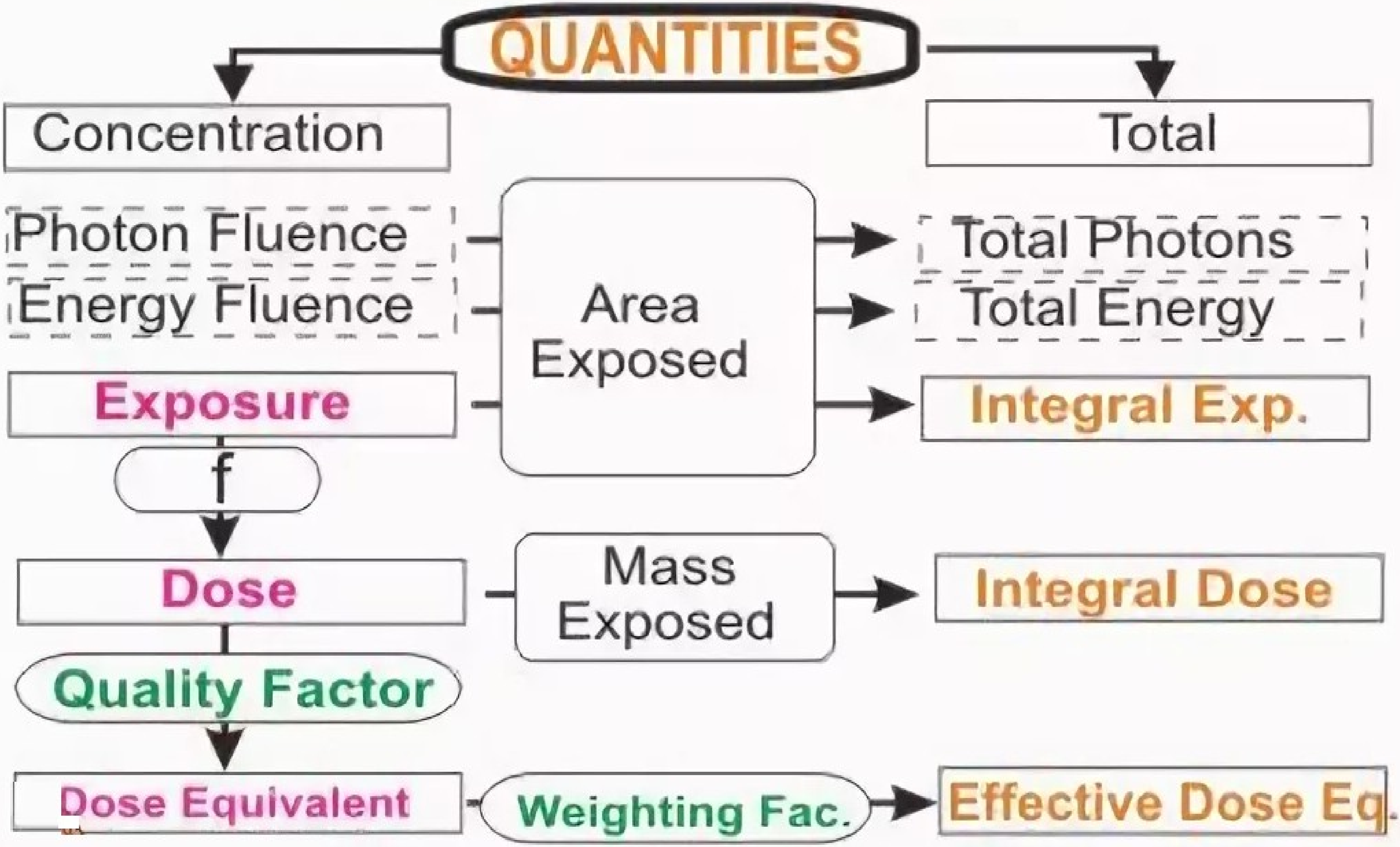
Quality Factor

The quality factor for each type of radiation is shown below:

Radiation	Quality Factor (***K***)
Alpha particles	20
Beta particles	1
Gamma rays	1

From this it can be seen that alpha radiation is the most ionising radiation out of the three types.

IONIZING RADIATION



Methods of protection against radiation

1. Protection by time *t* and distance *R*

Exposure dose:

$$X = \frac{\kappa_\gamma A t}{R^2}$$

A - activity

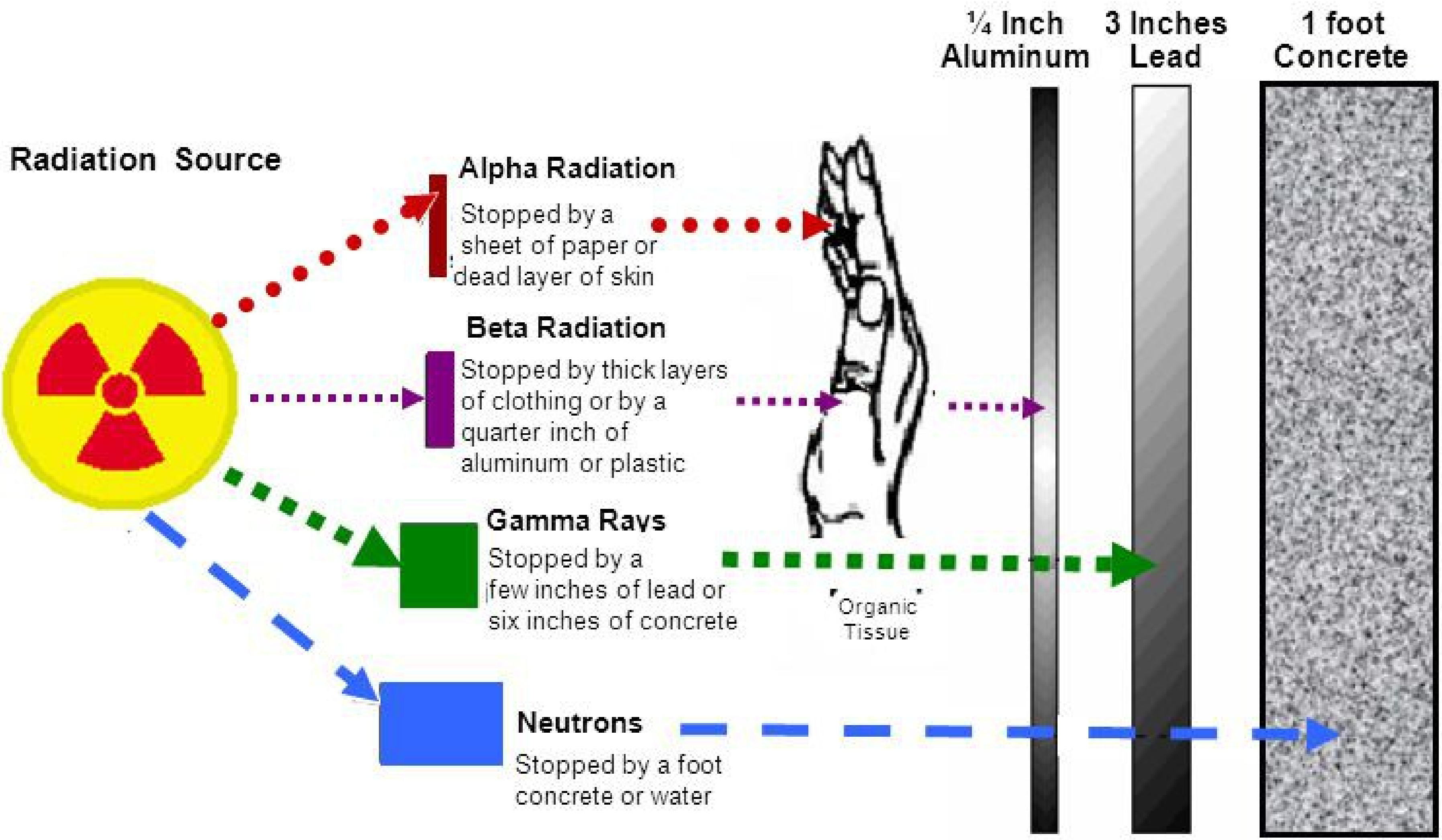
R - the distance from the radiation source

up to the site of exposure

k_γ-the constant of the radioactive isotope.

To reduce the damaging effect of radiation, it is necessary to be ***as far away*** *from the radiation source as possible and, if possible,* ***for less time****.*

Protection by the matter



Use of radioactive radiation:

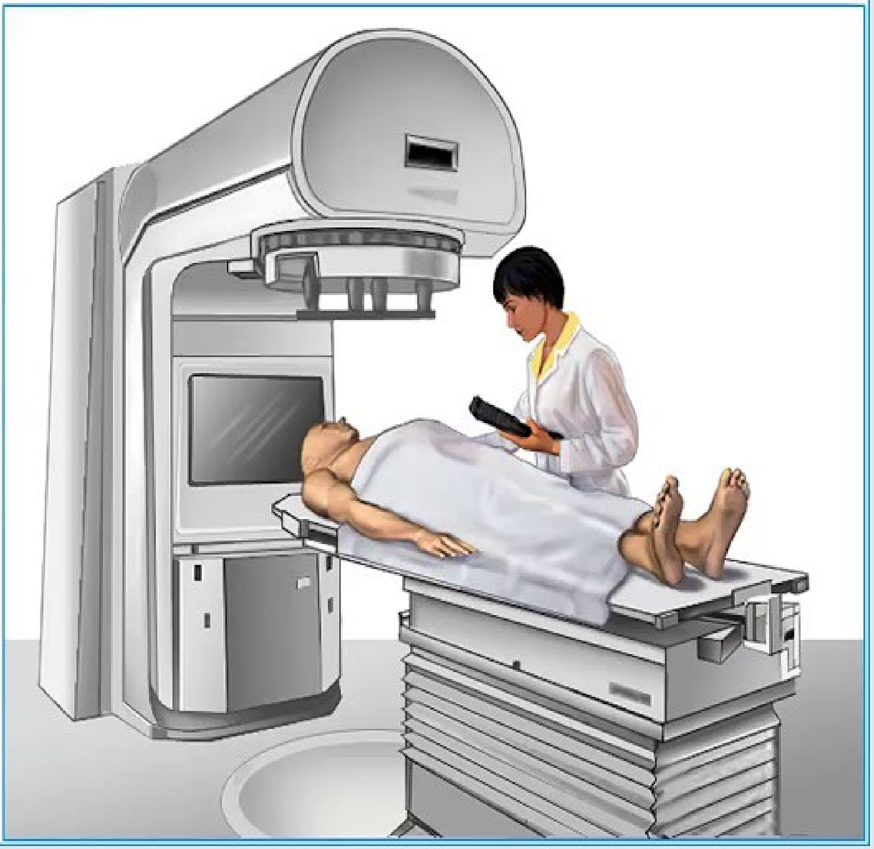
- diagnostics
- therapy

Radioactivity and medicine

1. Radiotherapy

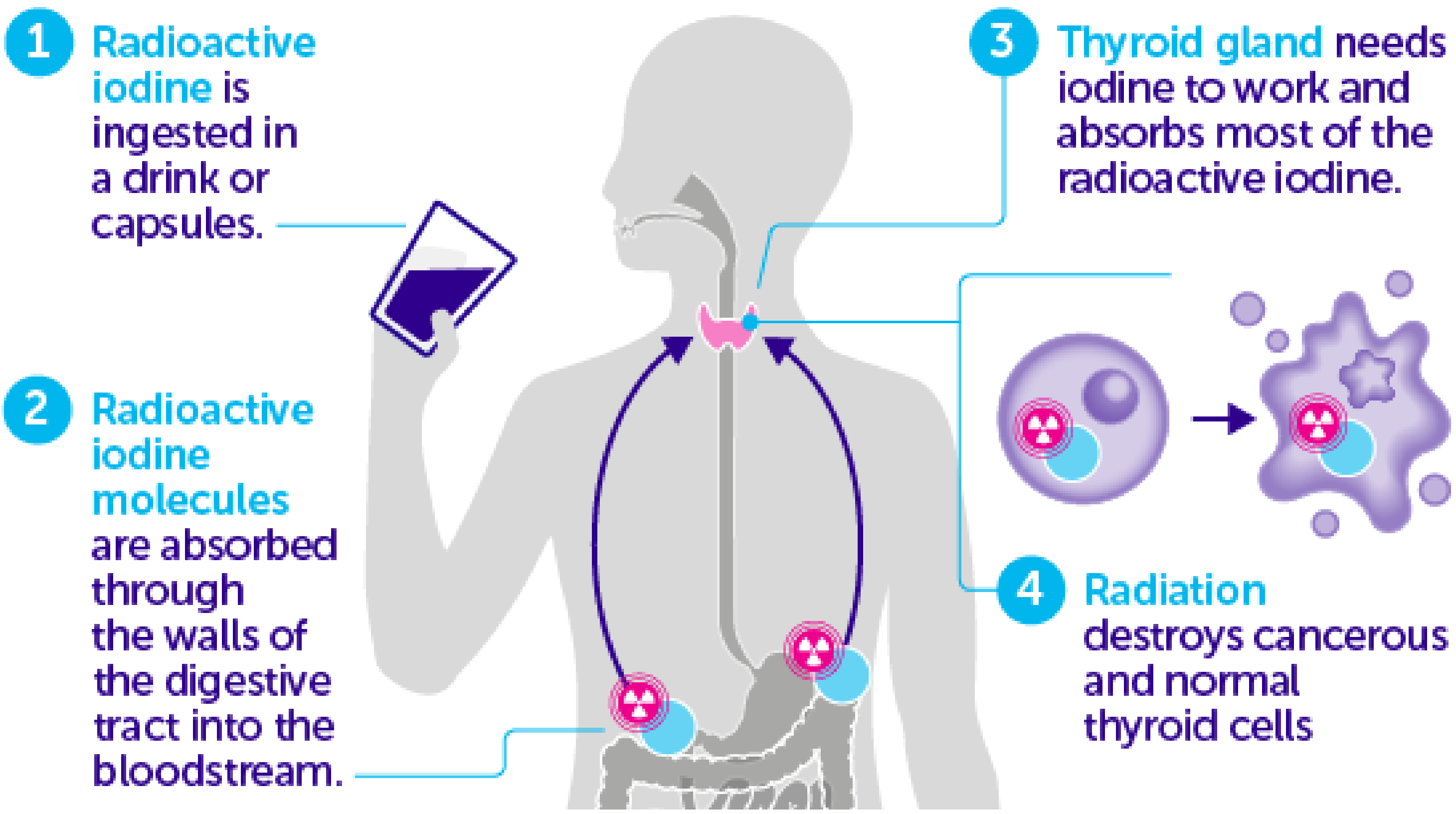
Radiotherapy is a method that consists on destroying cancerous cells by irradiating the tumor by γ rays.

This treatment must be achieved with a lot of precaution in order not to destroy the normal cells.

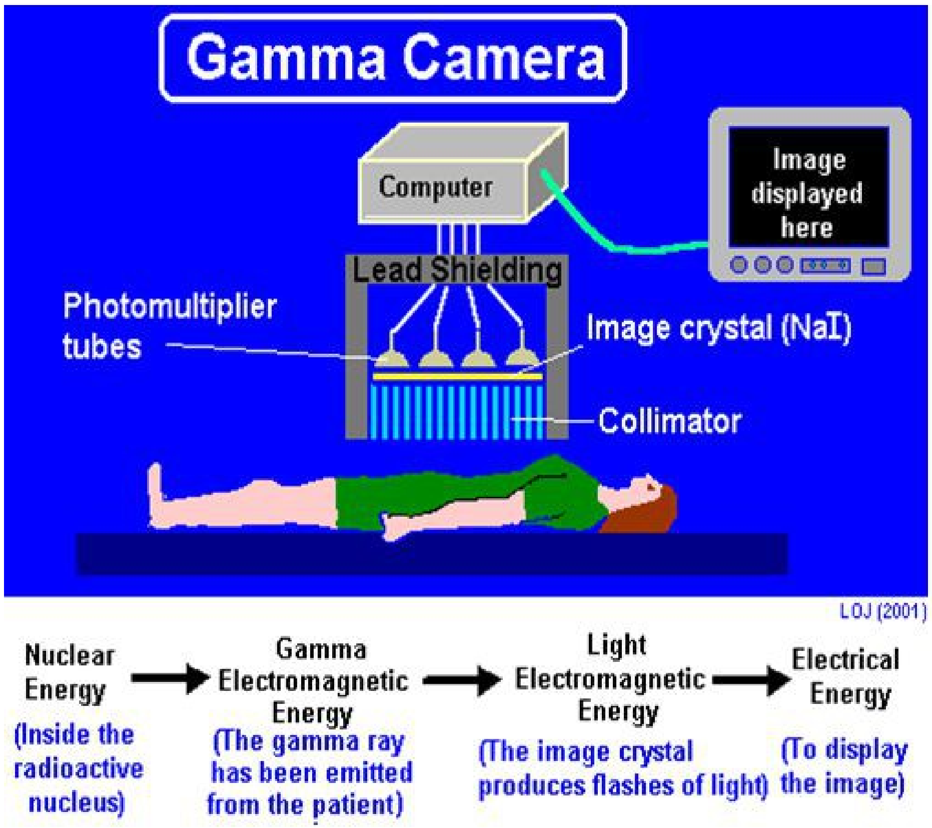


USING RADIOACTIVE LIQUID THERAPY TO TREAT THYROID CANCER

Iodine therapy specifically targets the thyroid and has very little effect on other parts of the body.



How nuclear medicine detects problems within different areas in our organ



- **In order to investigate a body organ. A suitable radioactive tracer having a particular affinity for that organ is injected into the blood stream this is up taken by the organ of interest which is then assessed by imaging with the gamma camera. The image beside explains how whole process works.**

Tasks and control questions:

1. Write down the law of radioactive decay. Give a characteristic of the quantities included in the law.
2. What is called activity, specific activity? In what units is it measured? How does the activity of an isotope change over time?
3. Give a characterization of radioactive emissions.
4. What are the characteristics of the interaction of charged particles with matter?
5. What is the radiation dose rate (P)? For what purpose is this concept introduced? In what units is P measured?
6. For what purpose is the definition "exposure dose X" introduced?

Follow up reading:

Obligatory:

1.Ремизов А.Н. Медицинская и биологическая физика: учебник. -М.: Дрофа, 2007.

2.D. C. Giancoli. Physics: Principles with Applications - 7th ed. Boston, Pearson, 2016

3.J. Walker, D. Halliday, R. Resnick. Principles of Physics - 10th ed. - [S. l.]. Wiley, 2014.

Additional:

1.Федорова В.Н. Краткий курс медицинской и биологической физики с элементами реабилитологии: учебное пособие. -М.: Физматлит, 2005.

2.Антонов В.Ф. Физика и биофизика. Курс лекций: учебное пособие.-М.: ГЭОТАР-Медиа, 2006.

3.Самойлов В.О. Медицинская биофизика: учебник. -СПб.: Спецлит, 2004.

Electronic resources:

1.electronic library system of Krasnoyarsk state medical University

2.Internet resources

3.Electronic medical library. Т.4. Физика и биофизика.- М.: Русский врач, 2004.

Thanks for your attention!

В Железногорск