Medical Biophysics

Introduction
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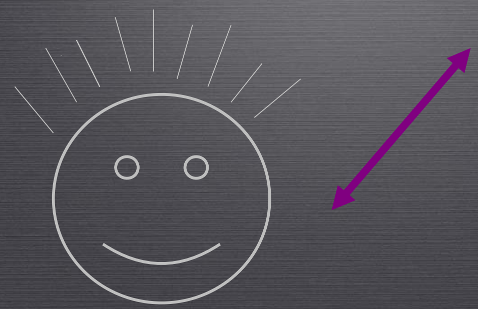
Medical Biophysics



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Medical Biophysics

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Keep smiling!

Medical biophysics --- ?

- ***Biophysics – scientific research field***

Medical biophysics --- ?

- ***Biophysics – scientific field***
  - physical methods (experimental and theoretical) applied to biological objects

Yearly Biophysics Congress in USA with ~7000 participants (2014 February, San Francisco), 4500 scientific works presented

Medical biophysics --- ?

- ***Medical Biophysics: Biophysical knowledge used for medical purposes***

Some examples…

A glance at an operating room…

A glance at an operating room…

Physical methods ?

Everywhere!

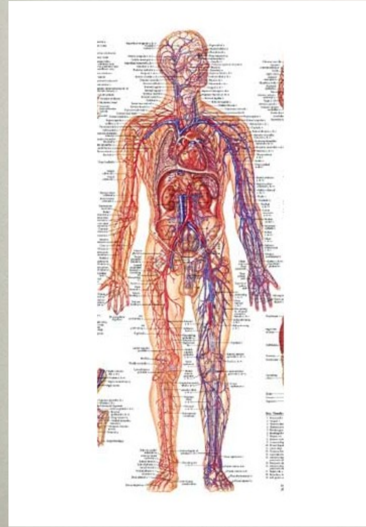
Could be: - IR laser
- electric knife

A glance at an operating room…

X-ray image amplifier

Problems in the circulation system …..

Circulation: physical phenomenon
Revealing the problem is by physical measurements and by understanding the physical laws

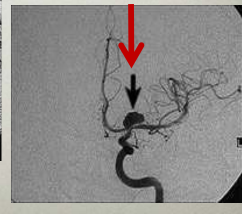


Example: attenuation of X-rays

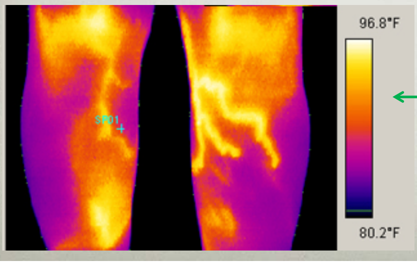
Image 1 (without *I* contrast) | Image 2 (with contrast) | ***DSA image***: subraction of Image1 from Image2

Normal frontal cerebral arteriogram

a ***large aneurysm*** at the left internal carotid artery in the brain.



Approach to blood circulation by **ultrasound echo** techniques



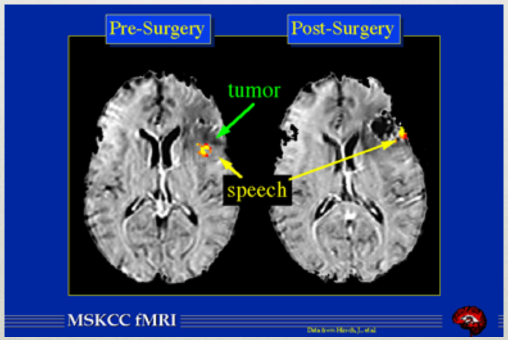
Thermography approach for blood circulation:

IR radiation intensity scan over the skin

Functional MRI
BOLD : Blood Oxygen Level Dependent signal

Ogawa, 1990

Stimulated centers in the brain yield increased T2 signal in proton magnetic resonance (MR)

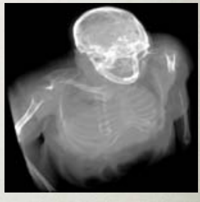


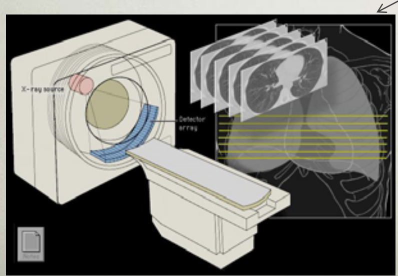
Medical diagnostic imaging – great achievements of physical knowledge and technical development

CT – methods: sectional imaging → 3D reconstruction

X-ray CT
SPECT
PET
Sonography
MRI

X-ray CT





Medical diagnostic imaging – great achievements of physical knowledge and technical development

Images of human head based on various physical parameters

Without knowing what parameter is coded into brightness, one can not use the information!

Medical diagnostic imaging – great achievements of physical knowledge and technical development

Images of human head based on various physical parameters

X-ray absorption capability
CT

H-density
MRI

Reflected US pulse intensity
Sonography

Deep understanding of metabolic processes

Schematics describing the process
physiology, biochemistry

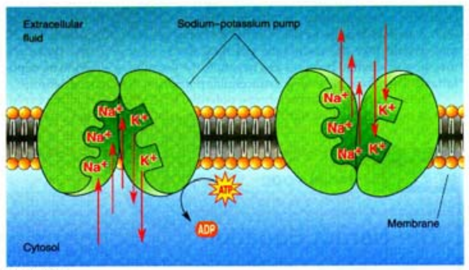
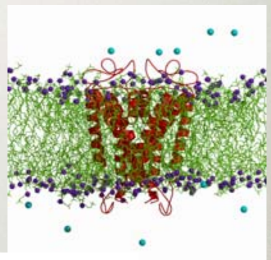
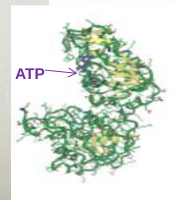


Figure 3.16
The sodium-potassium pump. This is a membrane-associated protein that transports ions across the membrane against their concentration gradients at the expense of metabolic energy.

Approach of physics →
structural information → basis for
drug design





Phosphoglycerate kinase
binding ATP

Structural information:-X-ray crystallograpgy
- NMR spectroscopy
- computer simulation methods

Outmost importance and significance of innovative application of physical knowledge in the field of Medicine

Let us start to build up this knowledge!

Radiations

The phenomenon of „radiation": ***energy propagation in space***

What kind of energy?

two classes of radiations**:**

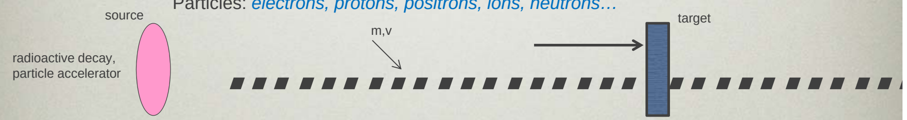
1. Kinetic energy is propagating

$$\boxed{E_{kin} = \frac{1}{2}mv^2}$$

particles with mass ***m*** are moving with velocity ***v***

1a. „Particle" radiations

Particles: *electrons, protons, positrons, ions, neutrons…*



In the beam of radiation, particles are moving with v velocity. In the material of the target the particles will transfer their E energy by collisions with constituting particles.

What kind of energy?

1. Kinetic energy is propagating

1.b only the state of motion is propagating

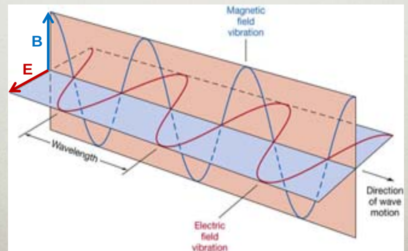
<u>example</u>: ***sound waves,*** audible- and ultrasound propagating in a medium

2. Electric and magnetic field is „propagating"

and generates electric and magnetic forces acting on particles of electric or magnetic properties

<u>example:</u> ***electromagnetic radiations*** – propagation does not require a medium (even in vacuum)

Change (in time) of electric and magnetic field vectors propagates in space



Classification based on the radiation effect on the target

1. Ionizing radiations

- particle radiations
- electromagnetic radiations with wavelengths shorter than visible light

harmful side-effects in human metabolism !

2. Non-ionizing radiations

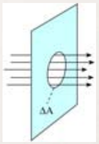
- visible light and electromagnetic radiations of longer wavelengths
- sound-ultrasound below the limiting intesity

The „strength" of radiation in the beam: intensity (J)

$$P = \frac{\Delta E}{\Delta t} \qquad P\left[\frac{Joule}{s} = W\right]$$

Intensity $$J = \frac{\Delta P}{\Delta A} \qquad J\left[\frac{W}{m^2}\right]$$

How much energy (ΔE) is propagating in the beam accross a unit area of cross section within a unit of time interval

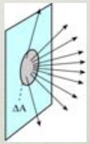


The intensity of radiation measured by a detector of surface ΔA

The strength of radiation characterizing the source : radiant emittance (M)

$$M = \frac{\Delta P}{\Delta A}$$

emitted power within a 2π of solid angle by a surface element ΔA of the source



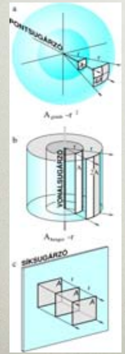
Surface area of a sphere of radius r : $4r^2\pi$
Surface area of a semi-sphere : $2r^2\pi$, for r=1 the surface area = 2π
Solid angle = 2π steradian means all the directions that lead from the source in the center to elements of a surrounding semi-sphere

How is the intensity of radiation at a certain distance related to the strength of the source, that is, to the radiant emittance?

How much energy (ΔE) is propagating in the beam accross a unit area of cross section within a unit of time interval depends on the geometry of the source.

The total emitted power may be distributed in the space along a variety of the set of directions.

Examples of sources with a variety of energy distributions in space



Point-like source
Propagation by spherical symmetry $\qquad J \sim \frac{1}{r^2}$

Line-shaped source
Propagation by cylindrical symmetry $\qquad J \sim \frac{1}{r}$

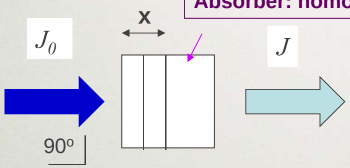
Planar source
parallel beams $\qquad$ J does not depend on the distance

If there is no loss of enery along with propagation

The intensity of radiation may be attenuated by material interactions

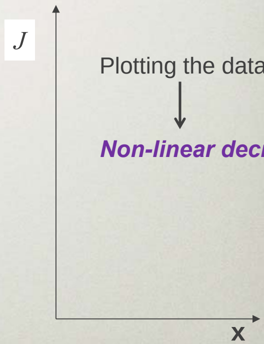
Attenuated : energy was lost along propagation
energy was consumed /"absorbed" by the medium

Absorber: homogeneous for quality and density



Layer-by -layer increase of the thickness (x) of absorber

Measuring ***J*** in function of **x**



Plotting the data
↓
Non-linear decrease!

Experiment (lab. practice)…

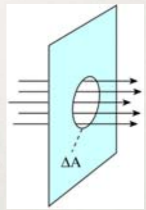
How to describe the observation?

What is the law of radiation intensity attenuation by absorption?

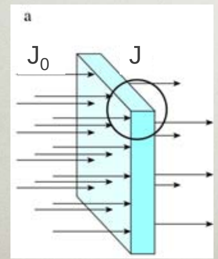
The quantities to formulate the change of intensity

$$P = \frac{\Delta E}{\Delta t} \qquad P\left[\frac{Joule}{s} = W\right]$$

$$J = \frac{\Delta P}{\Delta A} \qquad J\left[\frac{W}{m^2}\right]$$

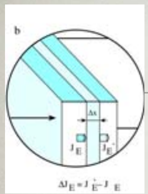


ΔE Δt
ΔA ΔP



$J<J_0$

To have a simple case, we consider parallel beams perpendicular to the surface of observation

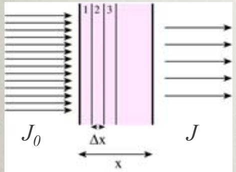


Observation in one elementary step of attenuation: The decrease is proportional to the thickness of absorber **Δx** and **J** what is the intensity at the layer-element

$$\Delta J = J_{E'} - J_E = -\mu \cdot \Delta x \cdot J$$

proportionality constant

stepwise application



$$J_1 - J_0 = -\mu\Delta x J_0 \rightarrow J_1 = J_0(1-\mu\Delta x)$$

$$J_2 - J_1 = -\mu\Delta x J_1 \rightarrow J_2 = J_1(1-\mu\Delta x) = J_0(1-\mu\Delta x)^2$$

$$J_k = J_0(1-\mu\Delta x)^k \qquad k = \frac{x}{\Delta x} = n\mu x \text{ if } n = \frac{1}{\mu\Delta x}$$

$$J_k = J(x) = J_0\left[\left(1-\frac{1}{n}\right)^n\right]^{\mu x} \qquad \mu\Delta x = \frac{1}{n}$$

$$\left(1-\frac{1}{n}\right)^{-n} \xrightarrow{n\to\infty} e = 2.7182818...... \rightarrow \boxed{J = J_0 e^{-\mu x}}$$

General conclusion from the Law of radiation attenuation

If in the elementary steps of a process we find the proportionality:

$$\underbrace{\Delta J}_{\text{change of a variable } (\Delta y)} = -\underbrace{\mu}_{\text{constant}} \cdot \underbrace{\Delta x}_{\text{change of the independent variable}} \cdot \underbrace{J}_{\text{magnitude of the variable before the change}}$$

then the elementary observation leads to the macroscopic relation

$$\boxed{J = J_0 \cdot e^{-\mu x}}$$

The independent variable is in the exponent of the natural base number „e"

In the form of an **exponential function**

There are many processes in nature that can be described by exponential functions

The exponential law of attenuation of radiation intensity by absorption.

$$\boxed{J = J_0 \cdot e^{-\mu x}}$$

attenuated intensity

Intensity incident to the surface of absorber

thickness of the medium

Conditions: set of parallel beams hit the surface of the medium at right angle, homogeneous medium

***μ*: linear absorption coefficient**

Depends on the

quality of radiation (wavelength of electromagnetic radiations, kinetic energy or kind of particles)

quality of the interacting medium (type of interaction)

quantity of absorbing molecules (density or concentration)

Radiations used in Medicine that are attenuated according to the exponential law

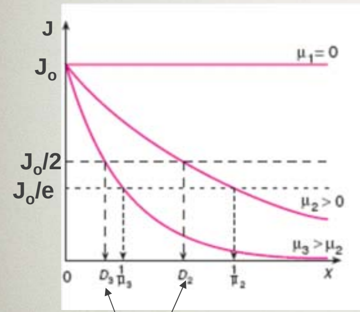
- Light (from UV through IR)
- X-ray
- γ-radiation
- β^- radiation up to x= 3-4 times the half value thickness D
- ultrasound

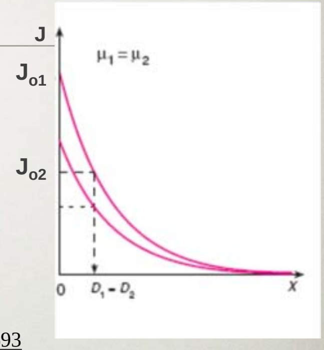
End

Thank you for your attention!

Graphic representation of the Law.

$$\boxed{J = J_0 \cdot e^{-\mu x}}$$





Half value thickness D:
Value of x where $J = J_o/2$

$$\mu = \frac{\ln 2}{D} = \frac{0.693}{D}$$

$$\delta = \frac{1}{\mu}$$

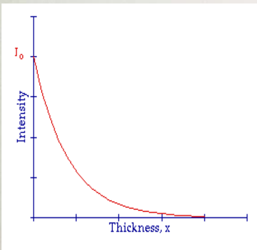
Determining μ from a measurement of intensity decay

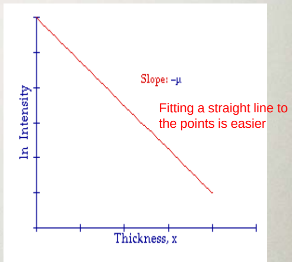
$$\boxed{J = J_0 \cdot 2^{-\frac{x}{D}}}$$

Determining μ from a measurement of intensity decay

Parameters ***D*** or δ are read from a curve of the best fit to experimental data

linear plotting → **semi-logarithmic transformation**





$$J = J_0 \cdot e^{-\mu x}$$ → **straight line**

$$\lg J = \lg J_0 - \mu x \lg e$$

$$\ln J = \ln J_0 - \mu x$$

$$\ln J = \frac{\lg J}{\lg e}$$