UNIVERSITAS SCIENTIARUM SZEGEDIENSIS
SZEGEDI TUDOMÁNYEGYETEM

Medical Physics 1.
Why do we teach, why do you learn medical physics?

The proper place of physics in the basic medical education (and in the medical profession)

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Professor & chairman

Department of Medical Physics & Informatics

Szeged, September 6, 2018.

How is physics positioned – why is physics reqiured for a medical student

- **The physics of life**

(circulation, propagation of excitation in the nervous system, respiration, vision, hearing etc..)

All kinds of vital signs involve physics – (mechanics-walking, standing, optics: vision, acoustics: hearing, electronics: operation of the nervous system, excitation coupling in the heart etc.).

Knowledge of basic (or advanced physics is essential for understanding the mechanism of the human body (Ohm's law, Boyle-Mariotte law, Bernoulli 's equation

Appropriate knowledge of physics is essential for understanding how devices used in medical diagnosis operate

- The practice of medicine involves the prevention, diagnosis, alleviation, and treatment of disease. Lots of devices are used in diagnosis. Who knows the principle of operation can also understand the limits of the devices (imaging techniques, radioisotopes, EKG, ultrasound etc.)

Physics in therapy (devices and procedures)

- Knowing physics makes the physician better in modern therapy and can help in developing new therapeutical approaches (laser surgery, radiation therapy, pacemakers etc. b),
- **Better knowledge of physics= better physician (and 2nd year medical student)**

HealthCare Activities

- Prevention
- Diagnosis
- Curative (therapeutic)
- Rehabilitation
- Palliative care (when cure is not possible)

Szegedi Tudományegyetem | Education - FoM 2014-2015

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DEPARTMENT OF MEDICAL PHYSICS AND INFORMATICS

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Education

Research

LATEST NEWS

Consultations (2014-05-19)
End-semester make-up occasions and laboratory test resits (2014-05-10)
Make-up of the 1st and 2nd practicals (2014-03-18)
Biostatistics consultations in the exam period (2013-12-04)

USEFUL LINKS

ELI-ALPS Workshop 2014
COST PHOTOTECH Training School
LAMELIS 2014
ETR
ETR CooSpace
University phonebook
Faculty of Medicine
University of Szeged
Wolfram Alpha

WHO IS ONLINE?

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[Magyar] [German]

Educational activities of the Institute

Faculty of Medicine
(2014/2015)

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1st semester

Medical Physics and Statistics I. (course codes: AOK-KA051, AOK-KA052)
- 1st year, 1st semester (compulsory course, 4 credits)

Cerebral blood flow and metabolism (course code: AOK-KA1027)
- 3rd year, 1st semester (elective course, 2 credits)

Basic biostatistics (course code: AOK-KA431)
- 4th and 5th year, 1st semester (lecture: 2 lessons per week, 2 credits)

Biostatistical calculations
- 1st year, 1st semester (compulsory elective practical course, 2 credits)

Previous years

Educational activities in year 2013/2014
Educational activities in year 2012/2013
Educational activities in year 2011/2012

Last Updated on Sunday, 31 August 2014 19:56

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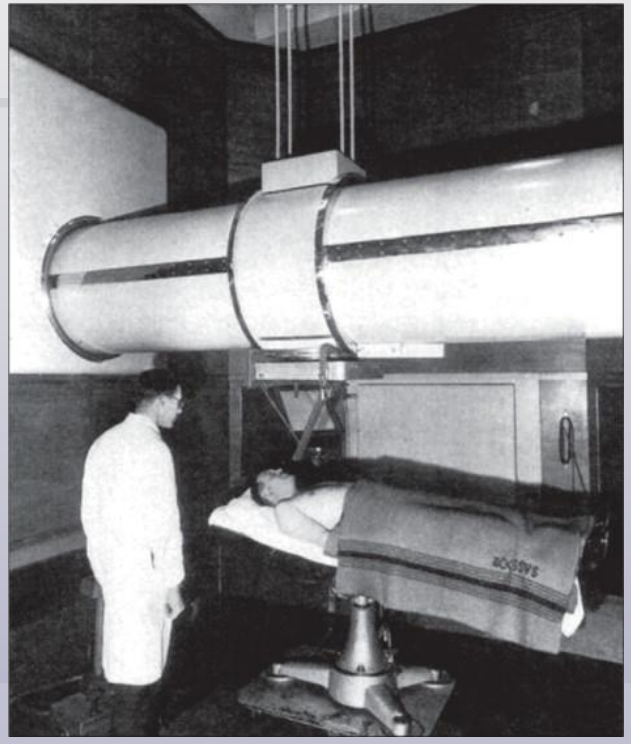
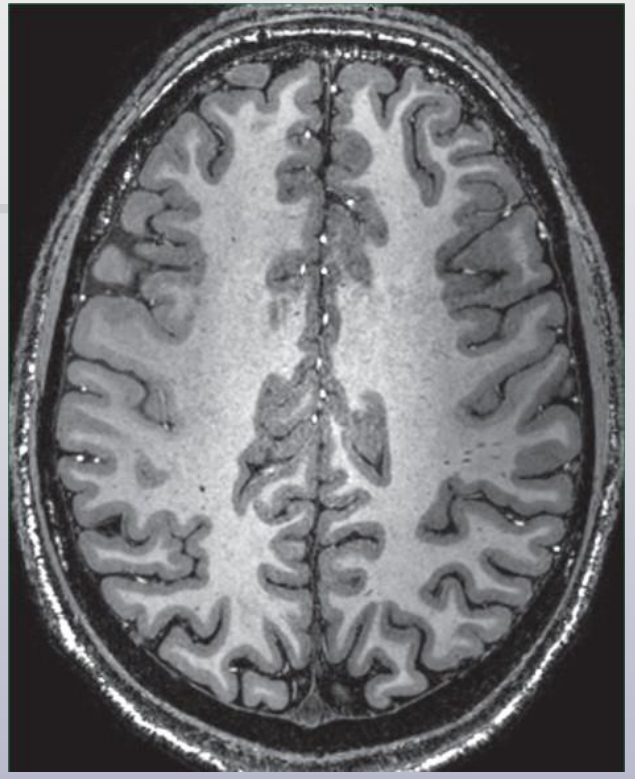
Some historical points

Reproduction of Hippocratic thermographyThis image was taken 8 min after a cloth soaked in potter's earth was applied to the volunteer's back. The rate at which the cloth dries is related to the temperature of the skin underneath. The region on the right-hand side had previously been heated with a compress. Reproduced from Ostuka and Togawa,[2] by permission of IOP Publishing.



One of the world's first megavoltage radiotherapy units at St Bartholomew's Hospital, London, UK, in 1937Reproduced from Laughlin,[45] by permission of the British Institute of Radiology.

Godfrey Hounsfield's first x-ray CT scanner Reproduced from Hounsfiled, by permission of the British Institute of Radiology.



High resolution (0·5 mm isotropic) image of the human head Acquired at 7 T with a magnetisation prepared rapid gradient echo sequence, showing excellent soft tissue (white matter or grey matter) contrast. Image courtesy of Sir Peter Mansfield Magnetic Resonance Centre, Nottingham, UK

How to study?

Studying medical physics, there is no problem with the amount of knowledge which is necessary to master, but with understanding the physical principles and their application. Memorisation without understanding will not be sufficient to have a success at the exam.

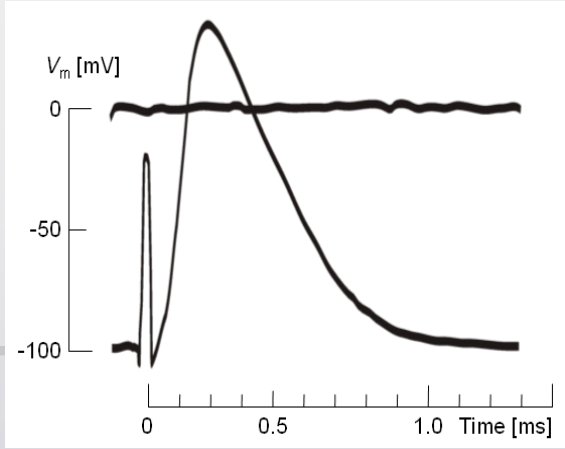
Buy a textbook of elementary physics- look at definitions, facts etc.

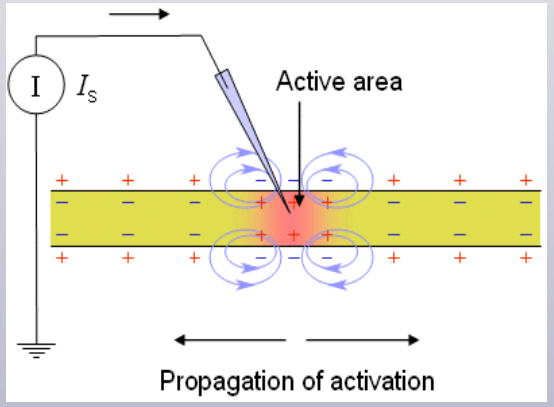
Try to understand principles

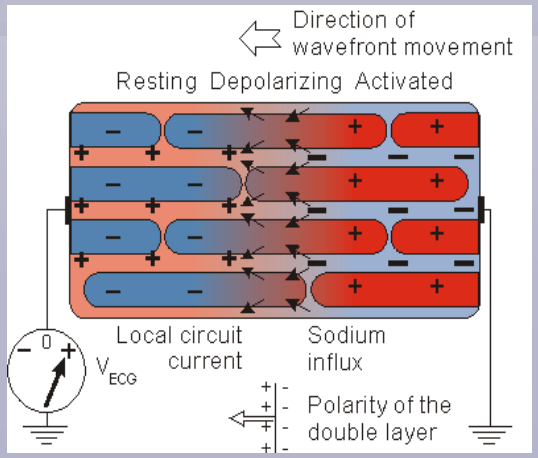
Read about interesting applications – wiki- internet etc.

Mechanism behind biopotentials

- When membrane stimulation exceeds a threshold level of about **20 mV**, so called action potential occurs:
  1. Sodium and potassium **ionic permeabilities** of the membrane change
  2. Sodium ion permeability increases very rapidly at first, allowing sodium ions to flow from outside to inside, making the inside more positive
  3. The more slowly increasing potassium ion permeability allows potassium ions to flow from inside to outside, thus returning membrane potential to its resting value
  4. While at rest, the Na-K pump restores the ion concentrations to their original values
- The number of ions flowing through an open channel >10^6/sec
- Body is an inhomogeneous volume conductor and these ion fluxes create measurable potentials on body surface

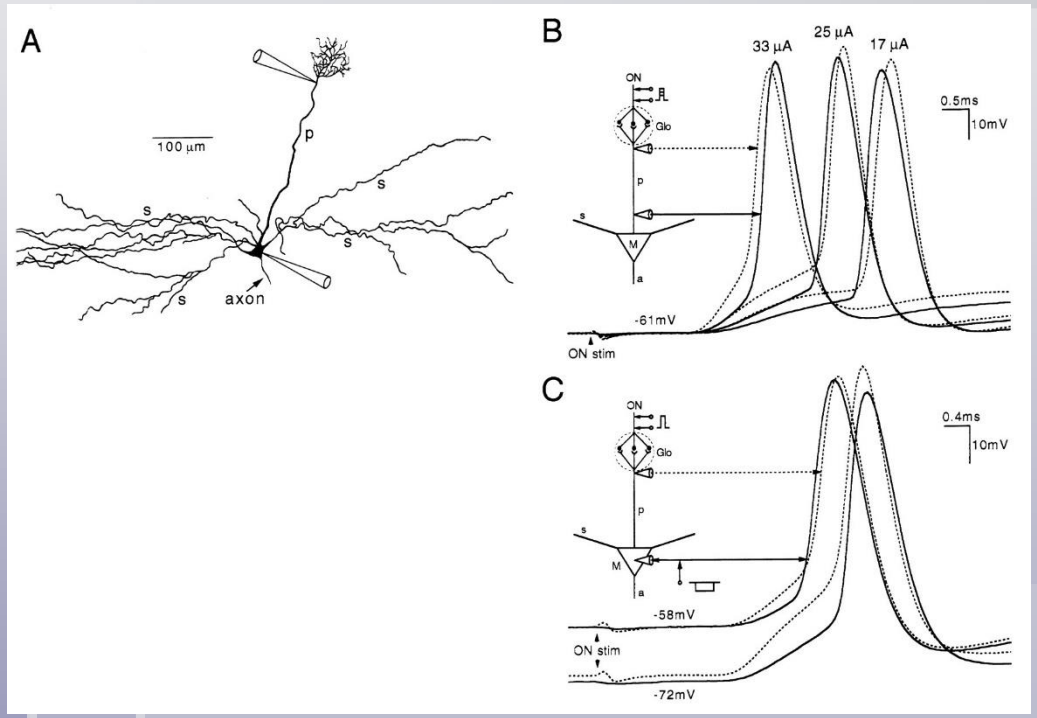






Electrophysiology:

This is the most important tool even today in investigating the properties of the nerve and muscle tissues – without electophysiology there is no further knowledge on physiology



Maxwell's equations are a set of four partial differential equations that describe how the electric and magnetic fields relate to their sources, charge density and current density . The equations are named after the Scottish physicist and mathematician James Clerk Maxwell who first published essentially the same equations in 1861. Individually, the equations are known as Gauss's law , Gauss's law for magnetism , Faraday's law of induction , and Ampère's law with Maxwell's correction- Often, two equations for the electromagnetic field tensor that give an equivalent relativistic formulation are also called the Maxwell equations.
Faraday's law of induction:

$$\oint_l E\,dl = -\int_A \frac{\partial B}{\partial t}\,dA$$

$$\mathrm{rot}E = -\frac{\partial B}{\partial t}$$

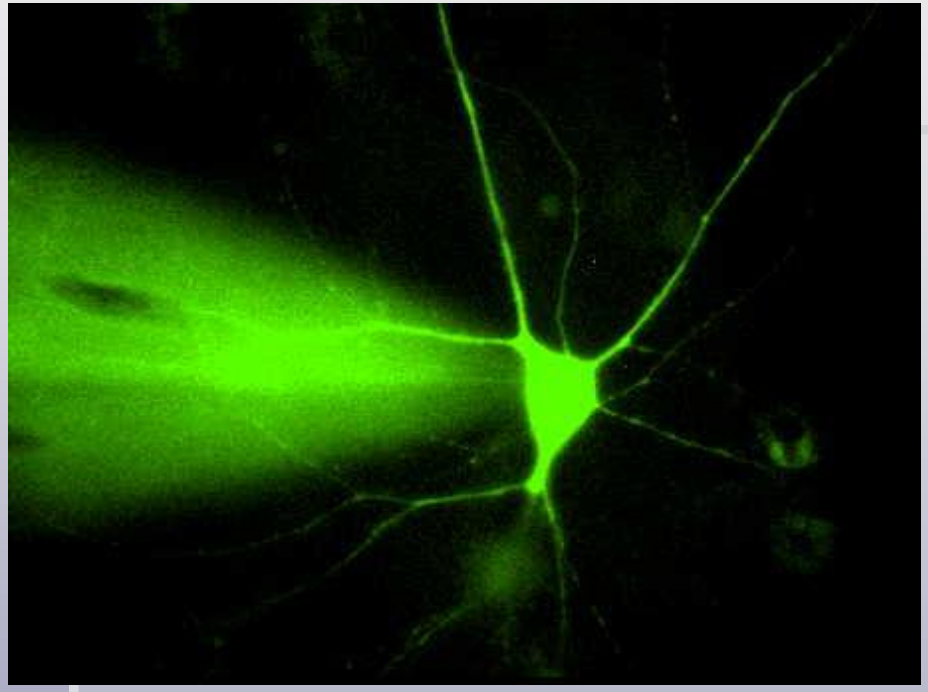
Don't worry, but the basic physics is required

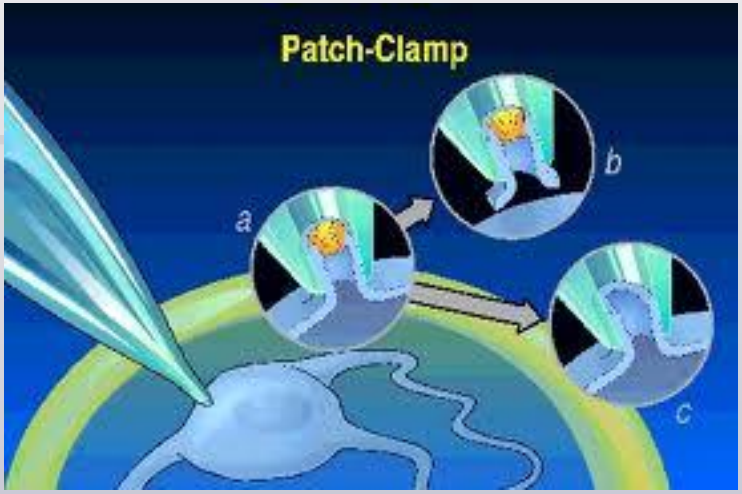
Ohm's, Gauss' etc. laws are valid and used in bioelectricity

Science > 1997.okt.17. > Chen et al., pp. 463 – 46- Nothing or all

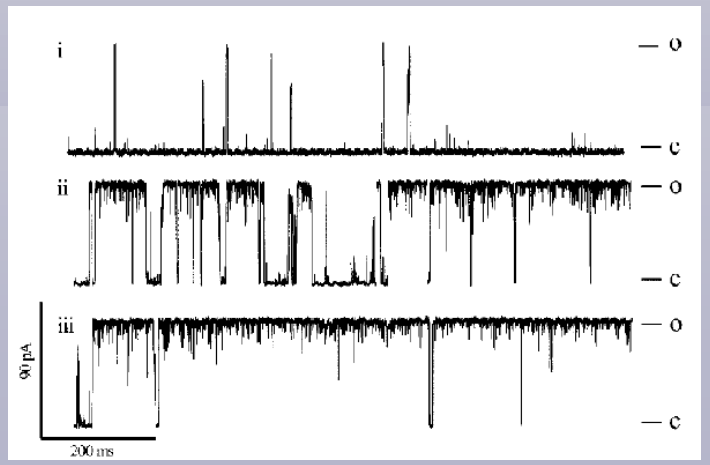
Please Please go over what you learned in high school!!
Electrical charge, current, resistance etc

„patch clamp” technique for investigating cell membrane ion channels

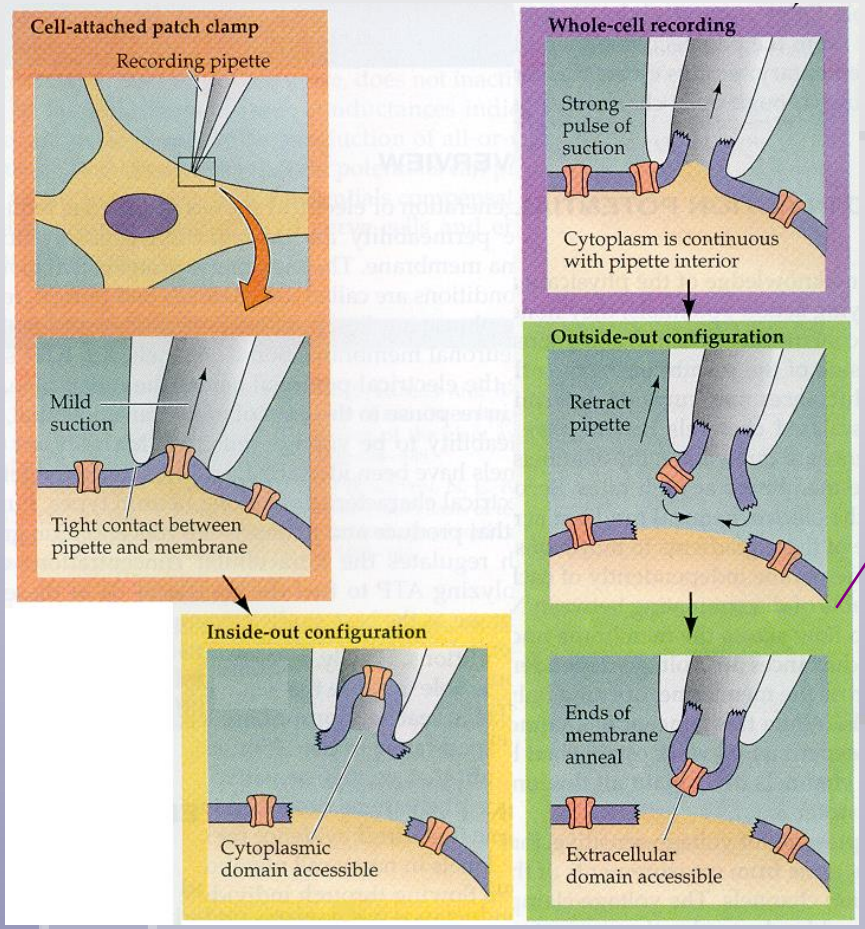


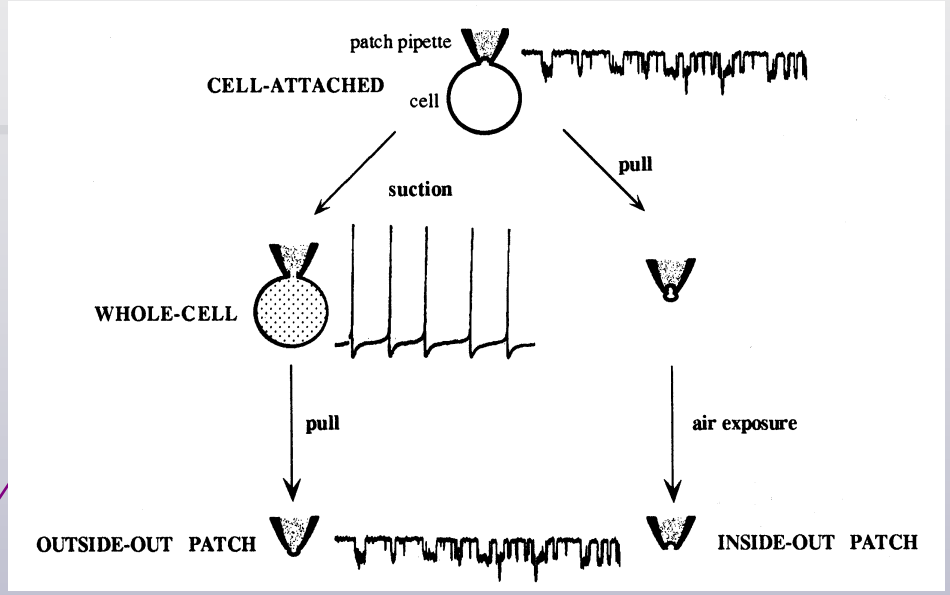


Channel currents (open or closed state)



Configurations of the patch-clamp technique





Currents are in the range in range pA (piko -10^{-12})
How much is the electrical charge (Q) if the ion channel is open for 2 ms ?
$Q=I*t$ (2 pA*2 ms)=$4*10^{-15}$As
1 coulomb (C) is the charge of 1 A current lasting for 1 s
1C=6.2×10^{18} (The **elementary charge**, usually denoted as e or sometimes q, is the electric charge carried by a single proton)
This channel conducted ~$24*10^3$ ~$2.4*10^4$ elementary charges
If it was Na^+ the n= $2.4*10^4$ ions, if Ca^{2+} it was the half!

Can you understand it without physics?

Units, Standards, SI System

- All measured physical quantities have units.
- Units are **VITAL** in physics!!
- In this course (and in most of the **modern world**, **except the USA!**) we will use (almost) exclusively the **SI system of units**.

  SI = "Systéme International" (French)

  More commonly called the "**MKS system**" (meter-kilogram-second) or more simply, "**the metric system**"

SI or MKS System

- Defined in terms of **standards** for length, mass (we'll discuss later), and time.
- **Length unit: Meter (m)** (kilometer = km = 1000 m)
  - **Standard meter**. Newest definition in terms of speed of light ≡ Length of path traveled by light in vacuum in (1/299,792,458) of a second!
- **Time unit: Second (s)**
  - **Standard second**. Newest definition ≡ time required for 9,192,631,770 oscillations of radiation emitted by cesium atoms!
- **Mass unit: Kilogram (kg)**
  - Discussed in detail later

The S.I. system

System International; an international "agreement" on the units used to describe physical parameters

Meter (m): 1 meter = 3.2808 feet = 1.0936 yards
1000 m = 0.6214 mile
1 mile = 1.6093 kilometers
Second (s): the only measure of time I know of!
Kilogram (kg): 1 kg = 1000 gram = 2.20462 pounds

Pressure: 1 Pascal (Pa) = 1 kg/m^2 = 0.00001 bar
Energy: 1 Joule (J) = 1 kg m^2/s^2 = 0.239 calorie
Power: 1 watt (W) = 1 J/s = 0.001341 horsepower

In scientific communication, we do not use "*feet*", "*ounces*", "*miles*", "*horse power*", "*psi*".

In fact, in most countries outside the United States, you see the S.I. units used by the general public (in traffic, weather, cookbooks, …).

Prefixes in the S.I. system

10^{-1}	0.1	deci	d	e.g., dm
10^{-2}	0.01	centi	c	e.g., cm
10^{-3}	0.001	milli	m	e.g., mm
10^{-6}	0.000001	micro	μ	e.g., μm
10^{-9}	0.000000001	nano	n	e.g., nm
10^{-12}	0.000000000001	pico	p	e.g., pm
10^{-15}	0.000000000000001	femto	f	e.g., fm
10^{1}	10	deca	da	e.g., da.m
10^{2}	100	hecto	h	e.g., hm
10^{3}	**1,000**	**kilo**	**k**	**e.g., km**
10^{6}	**1,000,000**	**mega**	**M**	**e.g., Ma**
10^{9}	**1,000,000,000**	**giga**	**G**	**e.g., Gy**
10^{12}	1,000,000,000,000	tera	T	e.g., TByte
10^{15}	1,000,000,000,000,000	peta	P	e.g., PByte

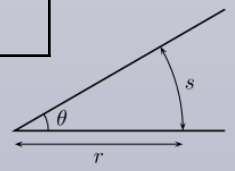
Dinosaur extinction happened 65 Ma (million years ago)
The Earth is 4.567 Gy (giga years or billion years) old
Earth's radius is 6371 km (kilometers).

SI base units

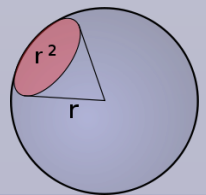
SI base unit

Base quantity	Name	Symbol
length	meter	m
mass	kilogram	kg
time	second	s
electric current	ampere	A
thermodynamic temperature	kelvin	K
amount of substance	mole	mol
luminous intensity	candela	cd

plane angle	radian [a]	rad	-	$m \cdot m^{-1} = 1$ [b]
solid angle	steradian [a]	sr [c]	-	$m^2 \cdot m^{-2} = 1$ [b]



1 *turn* = 360° = 2π rad



Examples of SI derived units

Derived quantity	Name	Symbol
area	square meter	m^2
Volume	cubic meter	m^3
speed, velocity	meter per second	m/s
Acceleration	meter per second squared	m/s^2
wave number	reciprocal meter	m^{-1}
mass density	kilogram per cubic meter	kg/m^3
specific volume	cubic meter per kilogram	m^3/kg
current density	ampere per square meter	A/m^2
magnetic field strength	ampere per meter	A/m
amount-of-substance concentration	mole per cubic meter	mol/m^3
Luminance	candela per square meter	cd/m^2
mass fraction	kilogram per kilogram, which may be represented by the number	1kg/kg = 1

SI derived unit

Derived quantity	Name	Symbol	Expression in terms of other SI units	Expression in terms of SI base units
frequency	hertz	Hz	-	s^{-1}
force	newton	N	-	$m \cdot kg \cdot s^{-2}$
pressure, stress	pascal	Pa	N/m^2	$m^{-1} \cdot kg \cdot s^{-2}$
energy, work, quantity of heat	joule	J	$N \cdot m$	$m^2 \cdot kg \cdot s^{-2}$
power, radiant flux	watt	W	J/s	$m^2 \cdot kg \cdot s^{-3}$
electric charge, quantity of electricity	coulomb	C	-	$s \cdot A$
electric potential difference, electromotive force	volt	V	W/A	$m^2 \cdot kg \cdot s^{-3} \cdot A^{-1}$
capacitance	farad	F	C/V	$m^{-2} \cdot kg^{-1} \cdot s^4 \cdot A^2$
electric resistance	ohm	Ω	V/A	$m^2 \cdot kg \cdot s^{-3} \cdot A^{-2}$
electric conductance	siemens	S	A/V	$m^{-2} \cdot kg^{-1} \cdot s^3 \cdot A^2$
magnetic flux	weber	Wb	$V \cdot s$	$m^2 \cdot kg \cdot s^{-2} \cdot A^{-1}$
magnetic flux density	tesla	T	Wb/m^2	$kg \cdot s^{-2} \cdot A^{-1}$
inductance	henry	H	Wb/A	$m^2 \cdot kg \cdot s^{-2} \cdot A^{-2}$
Celsius temperature	degree Celsius	°C	-	K
luminous flux	lumen	lm	$cd \cdot sr$ [c]	$m^2 \cdot m^{-2} \cdot cd = cd$
illuminance	lux	lx	lm/m^2	$m^2 \cdot m^{-4} \cdot cd = m^{-2} \cdot cd$
activity (of a radionuclide)	becquerel	Bq	-	s^{-1}
absorbed dose, specific energy (imparted), kerma	gray	Gy	J/kg	$m^2 \cdot s^{-2}$
dose equivalent [d]	sievert	Sv	J/kg	$m^2 \cdot s^{-2}$
catalytic activity	katal	kat		$s^{-1} \cdot mol$

SI derived unit

Derived quantity	Name	Symbol	Expression in terms of other SI units	Expression in terms of SI base units
plane angle	radian [a]	rad	-	$m \cdot m^{-1} = 1$ [b]
solid angle	steradian [a]	sr [c]	-	$m^2 \cdot m^{-2} = 1$ [b]
frequency	hertz	Hz	-	s^{-1}
force	newton	N	-	$m \cdot kg \cdot s^{-2}$
pressure, stress	pascal	Pa	N/m^2	$m^{-1} \cdot kg \cdot s^{-2}$
energy, work, quantity of heat	joule	J	$N \cdot m$	$m^2 \cdot kg \cdot s^{-2}$
power, radiant flux	watt	W	J/s	$m^2 \cdot kg \cdot s^{-3}$
electric charge, quantity of electricity	coulomb	C	-	$s \cdot A$
electric potential difference, electromotive force	volt	V	W/A	$m^2 \cdot kg \cdot s^{-3} \cdot A^{-1}$
capacitance	farad	F	C/V	$m^{-2} \cdot kg^{-1} \cdot s^4 \cdot A^2$
electric resistance	ohm	Ω	V/A	$m^2 \cdot kg \cdot s^{-3} \cdot A^{-2}$
electric conductance	siemens	S	A/V	$m^{-2} \cdot kg^{-1} \cdot s^3 \cdot A^2$
magnetic flux	weber	Wb	$V \cdot s$	$m^2 \cdot kg \cdot s^{-2} \cdot A^{-1}$
magnetic flux density	tesla	T	Wb/m^2	$kg \cdot s^{-2} \cdot A^{-1}$
inductance	henry	H	Wb/A	$m^2 \cdot kg \cdot s^{-2} \cdot A^{-2}$
Celsius temperature	degree Celsius	°C	-	K

The purpose of the „Medical physics” course 2.

- The understanding of the basic operation theory of diagnostic devices (design new devices) throughout the knowledge of physics of the living organisms
- **Diagnosis**
- E.g.: examination of the auditory pathway
- Case history: 48 yrs old, 172 cm high, 85 kg male suddenly lost hearing on the left ear, he had some dizziness in the morning
- After some hours the symptoms still persists, so he visits the family practitioner (GP)
- See what’s happening

What is a Medical Device?

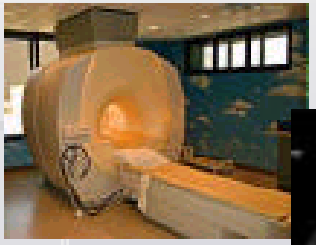
"any instrument, apparatus, appliance, material or other article, whether used alone or in combination, including the software necessary for its proper application intended by the manufacturer to be used on human beings for the purpose of:

- diagnosis, prevention, monitoring, treatment or alleviation of disease,
- diagnosis, monitoring, treatment, or alleviation of or compensation for an injury or handicap,
- investigation, replacement or modification of the anatomy or of a physiological process,
- control of conception

and which does not achieve its principal intended action in or on the human body by pharmacological, immunological or metabolic means, but which may be assisted in its function by such means." (MDD Article 1(2a))

Medical Imaging Devices (*in vivo* diagnosis)

- X-ray projection imaging
- Computerised Tomography (CT)
- Ultrasound (USI), Doppler imaging
- Magnetic resonance imaging (MRI)
- Radionuclide imaging (nuclear medicine)
- Thermography
- Etc.



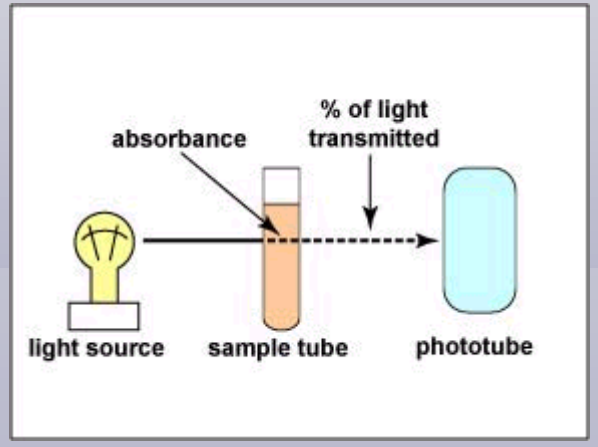
Medical Imaging Devices (*in vivo* diagnosis)

Theoretical background:

Ionising radiation (origin, measurement, interactions with matter), properties of atoms and nucleus, radioactivity, basic terms of acoustics, electromagnetic spectrum….

Medical Laboratory Devices (*in vitro* diagnosis)

- sample separation, centrifugation etc
- electrophoresis, capillary electrophoresis
- pH / ISE meters
- particle / cell counters
- spectrophotometers
- flow cytometry
- microscopy
- HPLC (chromatography)
- clinical chemistry
- haematology
- immunology
- scintillation systems
- genetic analysis



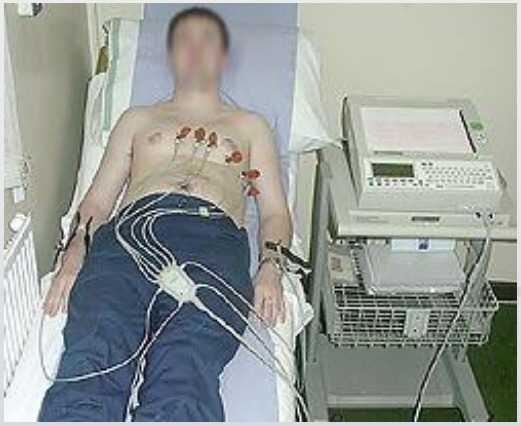
Physiological Measurement Devices (*in vivo* diagnosis)

- Instruments for measuring physical and chemical variables *in vivo*
- Thermometers
- Cardiovascular physiology: blood pressure monitors, flowmeters, pulsed Doppler US systems
- Electrophysiology: ECG, EEG, EMG
- Audiology and ophthalmology
- Respiratory physiology: spirometers, pulse oximetry, impedance pneumograph….
- Endoscopes

Physiological Measurement Devices (*in vivo* diagnosis)

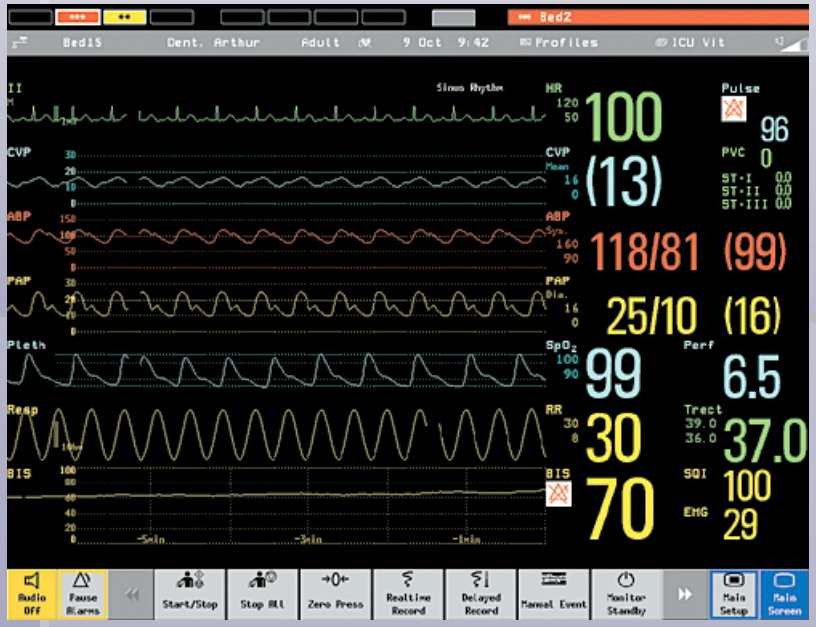
Theoretical background:

Introduction to thermodynamics, basic laws of hydrodynamics, origin of bioelectric potentials, properties of sound and light, ear and hearing, eye and vision, mechanical properties of living matter…



ECG (aka EKG)

Measuring lung capacity using a spirometer.

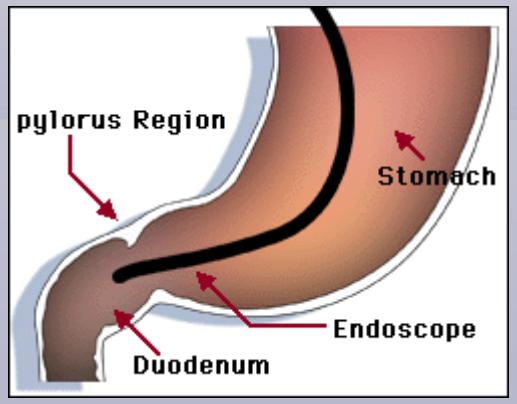


Screen of a multipurpose clinical monitor

sphygmomanometer

Paediatric Intensive Care

Endoscopy



Radiotherapy Devices

- X-ray and electron, resp. hadron beams from accelerators (shape, direction, and intensity of beam changed often continuously)
- gamma-ray beams from tele-isotope radioactive sources like Co-60
- treatment planning systems
- simulators
- brachytherapy
- dosimeters

Linear accelerator

Leksell gamma knife

Radiotherapy Devices

Theoretical background:

Ionising radiation (origin, measurement, interactions with matter), properties of atom nucleus, radioactivity, biological effects of ionising radiation, dosimetry….

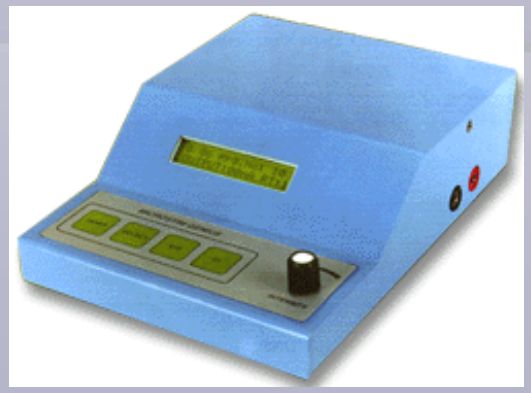
Physical therapy Devices

- Electrotherapy
- UV and IR therapy
- Shortwave diathermy
- Ultrasound therapy
- Laser therapy

Ultrasound therapy unit

Shortwave diathermy

Muscle stimulator

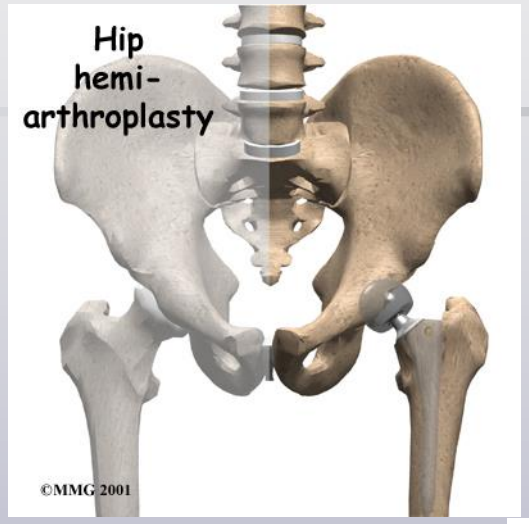


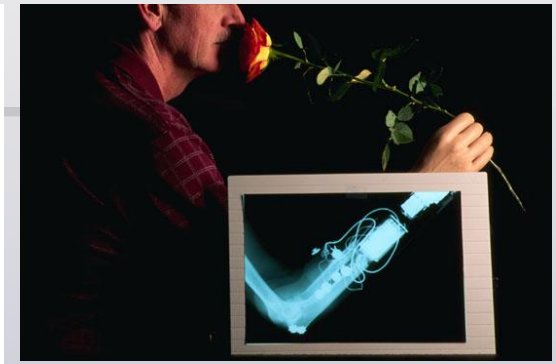
Laser therapy unit

Surgical Theatre Devices

Surgical Theatre Devices

Prosthetic Devices - Implants

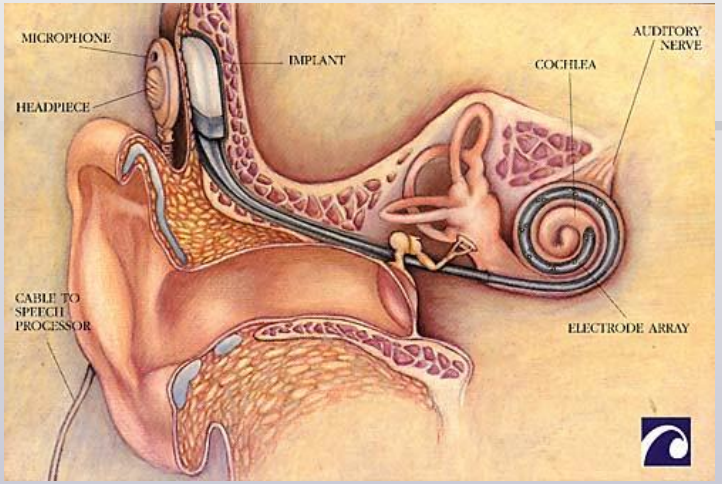




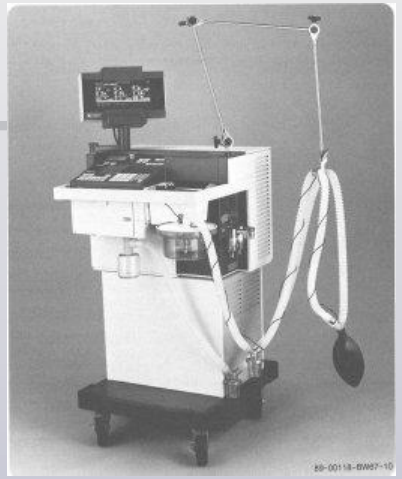
Robotic device for knee prosthesis implantation

Prosthetic Devices – „Artificial Organs“

Artificial heart

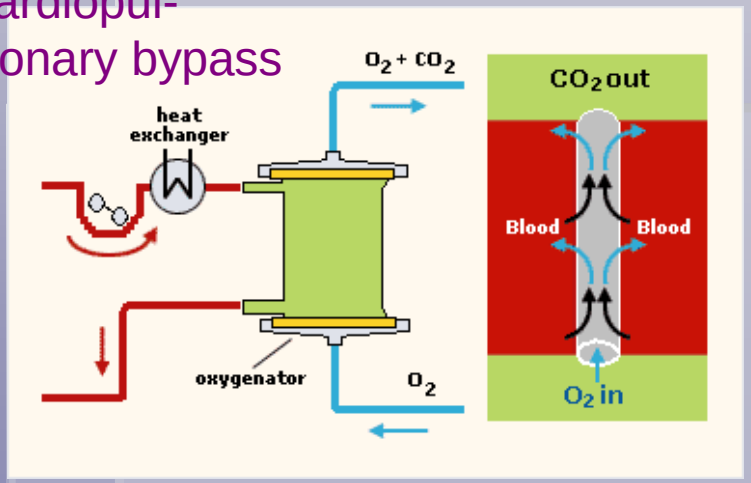


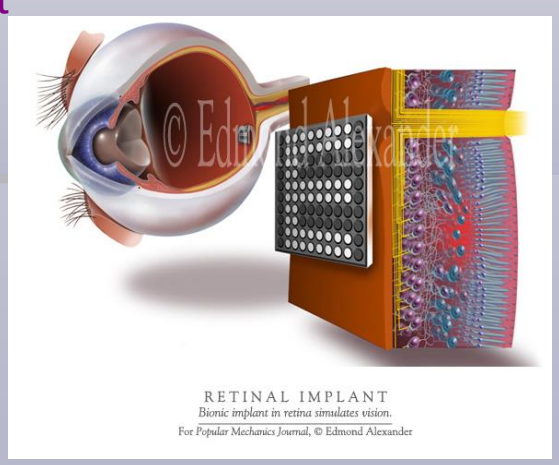
Cochlear implant



Ventilator

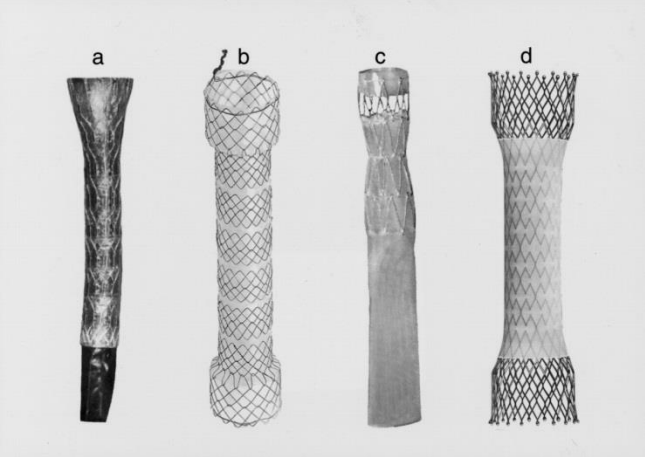
Cardiopul-
monary bypass

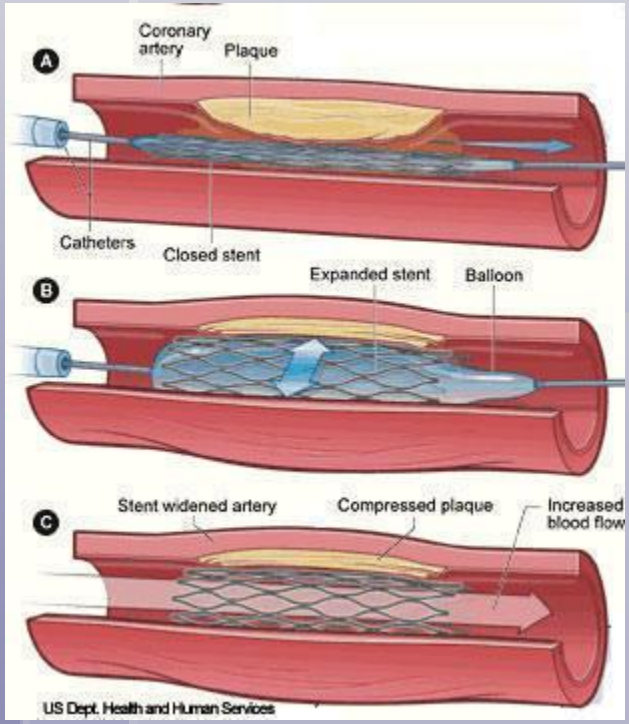




Retinal implant

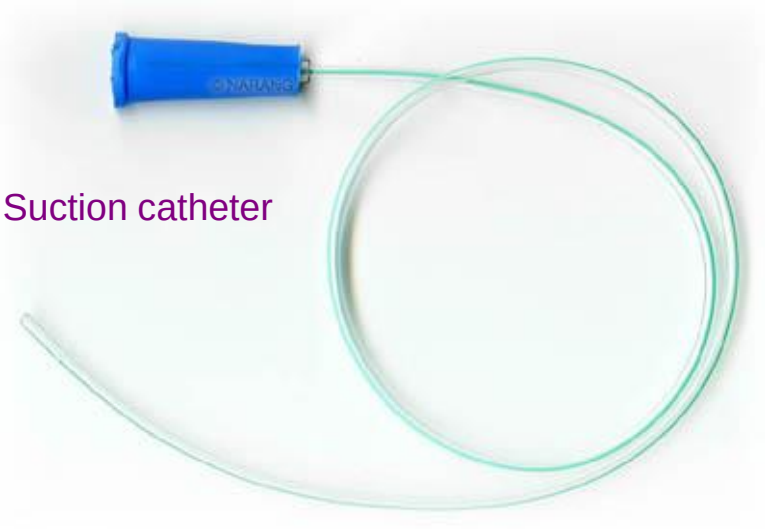
Prosthetic Devices – „Artificial Org…"





- **Stents** are inserted into the damaged blood vessels, oesophagus etc. They are often made of a metal with a „shape memory" – nitinol, which adopts the intended shape when heated to body temperature.

Disposable Medical Devices



Suction catheter

I.V. cannulae

Umbilical cord clamp

What has been learned so far?

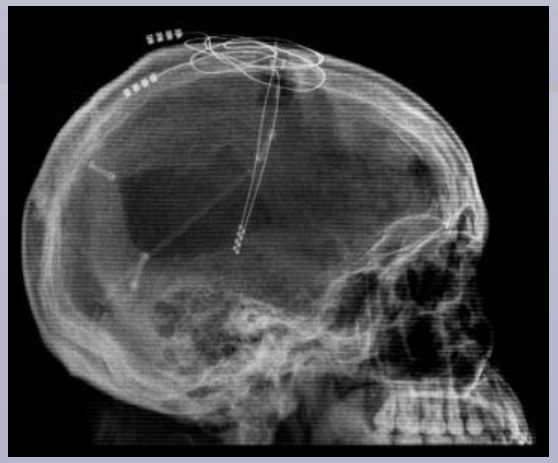
- Medicine can not be understood without strong background in physics
- diagnosis,
- Therapy
- PHYSICS, PHYSICS PHYSICS

3D CARTESIAN COORDINATE SYSTEMS

- The field of computer graphics, X-ray therapy, certain kinds of neurosurgery used in the medicine relies heavily on vector calculations and matrix transformations.
- These calculations, along with the Cartesian coordinate system, are based on numbers indicating distances.
- The Cartesian coordinate system is consequently the most fundamental system for the unique identification of arbitrary points in space.

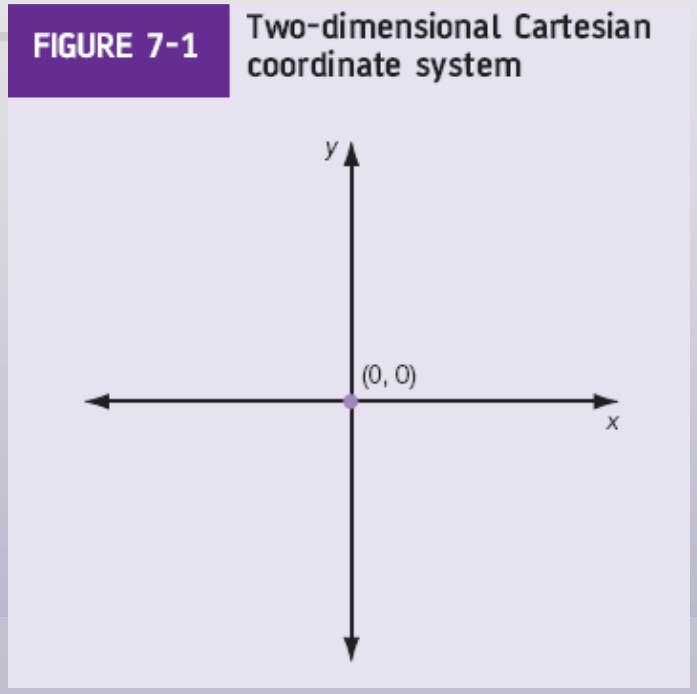
3D CARTESIAN COORDINATE SYSTEMS

- Two kinds of Cartesian coordinate systems:
  - two-dimensional
  - three-dimensional



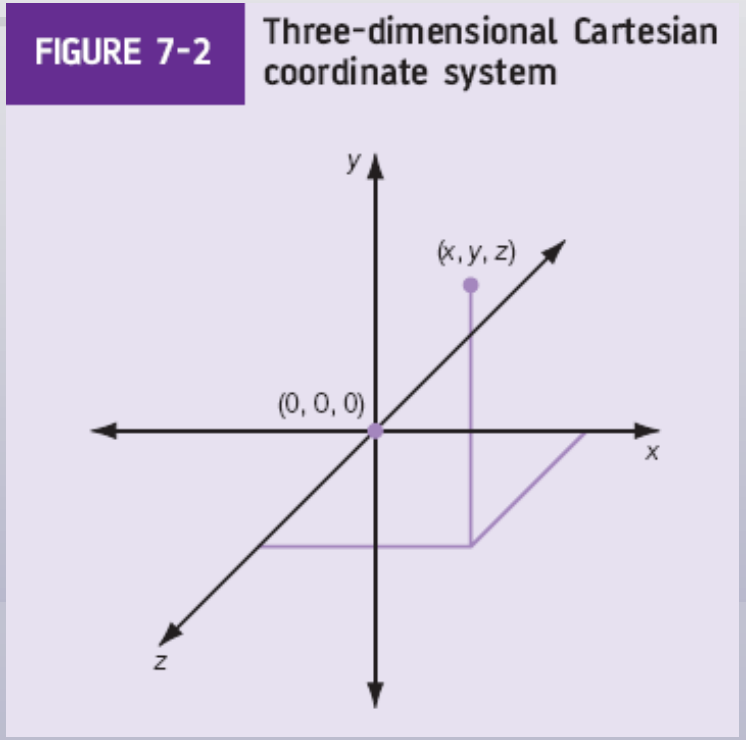
3D CARTESIAN COORDINATE SYSTEMS

- A two-dimensional Cartesian coordinate system consists of an origin intersected by two axes perpendicular to each other.
  - The vertical axis is known as the y-axis and the horizontal axis, the x-axis.



3D CARTESIAN COORDINATE SYSTEMS

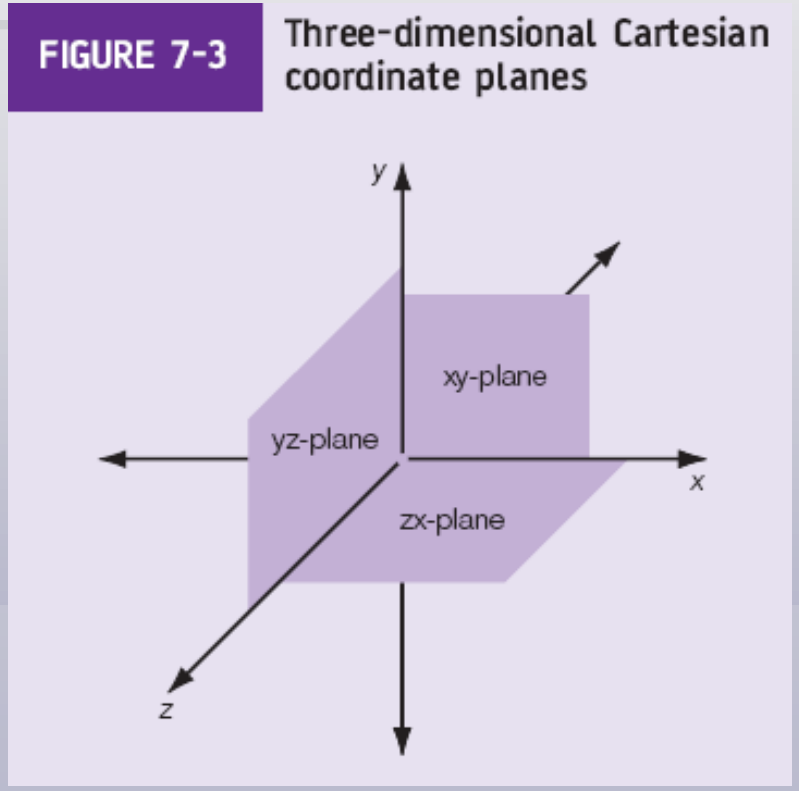
- The three-dimensional Cartesian coordinate system provides an additional dimension for spatial measurement by means of a diagonal z-axis.



3D CARTESIAN COORDINATE SYSTEMS

- Vertex coordinates are written in the form

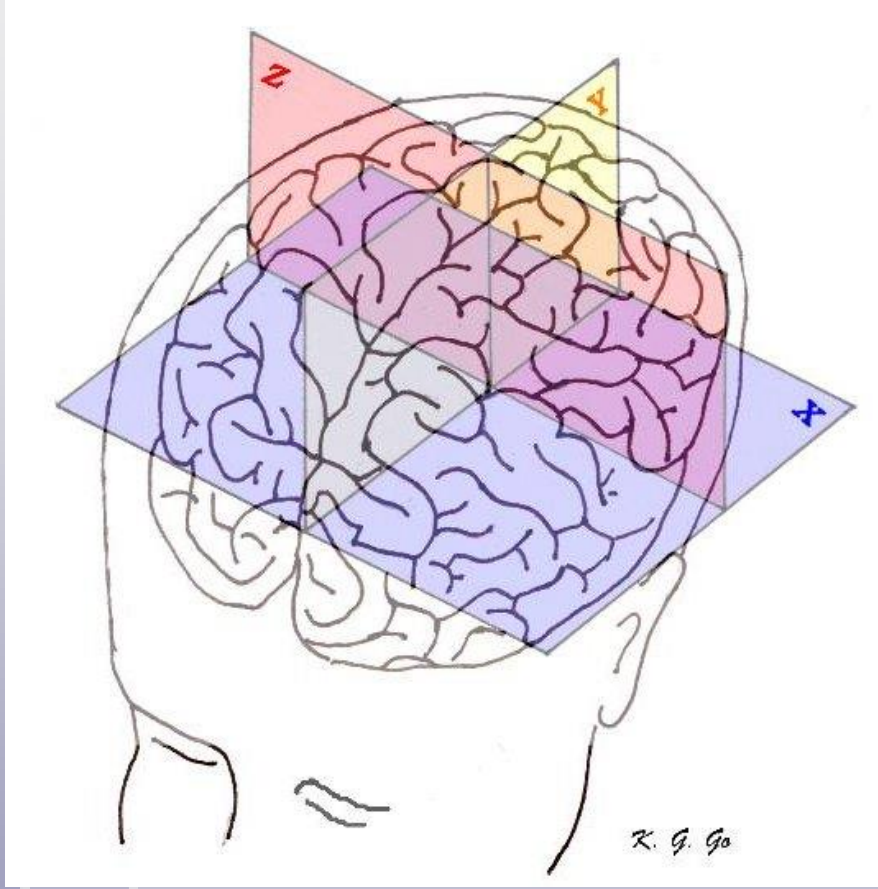
  (x, y, z), with xy-, xz-, and yz-planes dividing the coordinate space into eight areas.



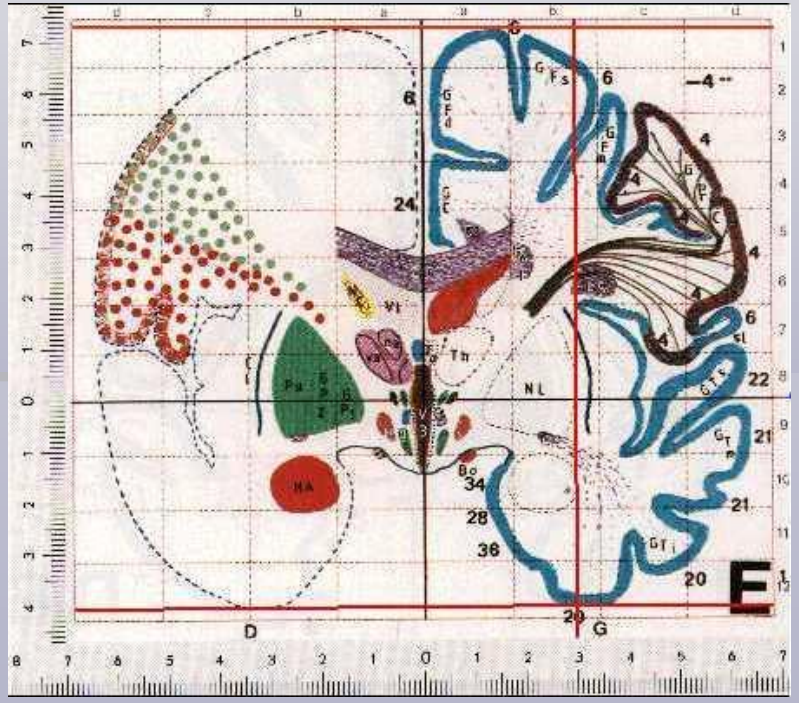
3D CARTESIAN COORDINATE SYSTEMS

- independent coordinate systems function on the principle of translating between world and device or screen coordinates (the coordinate system used by the graphics display).
- In the advanced medical praxis individual 3D picures help in finding the regions under treatment

Stereotaxic spot identification in the human brain



Post mortem slides
Healthy 60 yrs old male
Serial slices



- Y axis commissura anterior - commissura posterior)

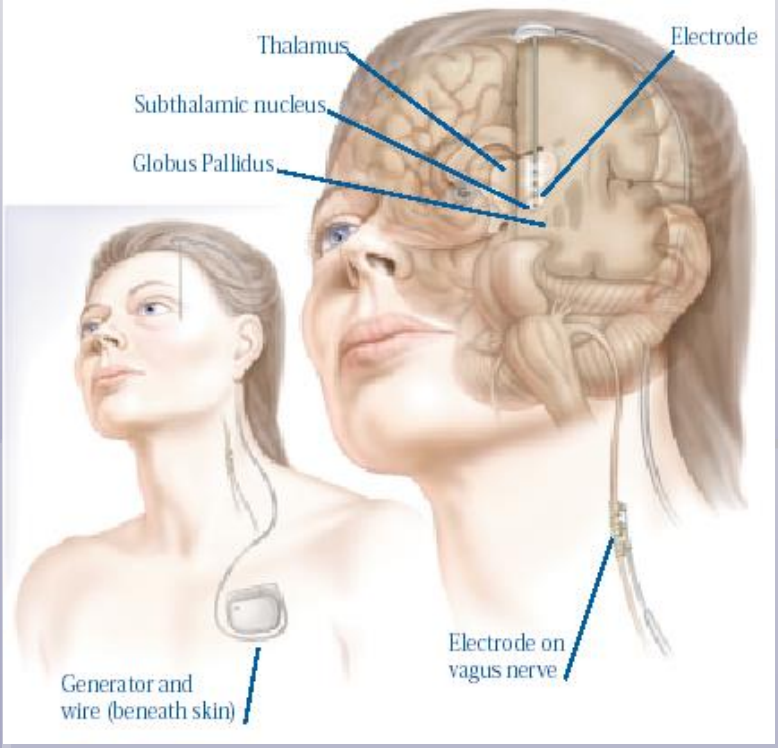
Example of treatment by means of gamma knife (GK)

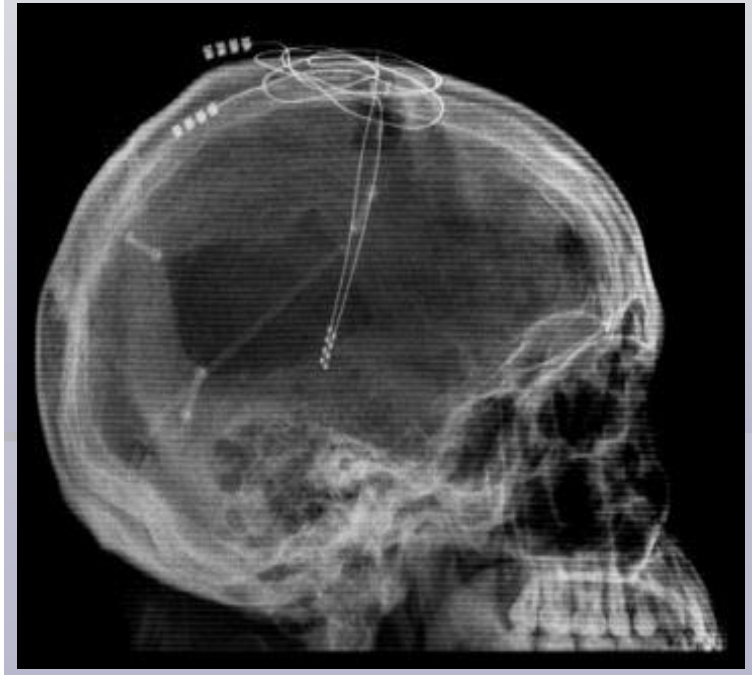
frontal lobe metastasis

several months after GK radiosurgery

Controlling Parkinson's Disease

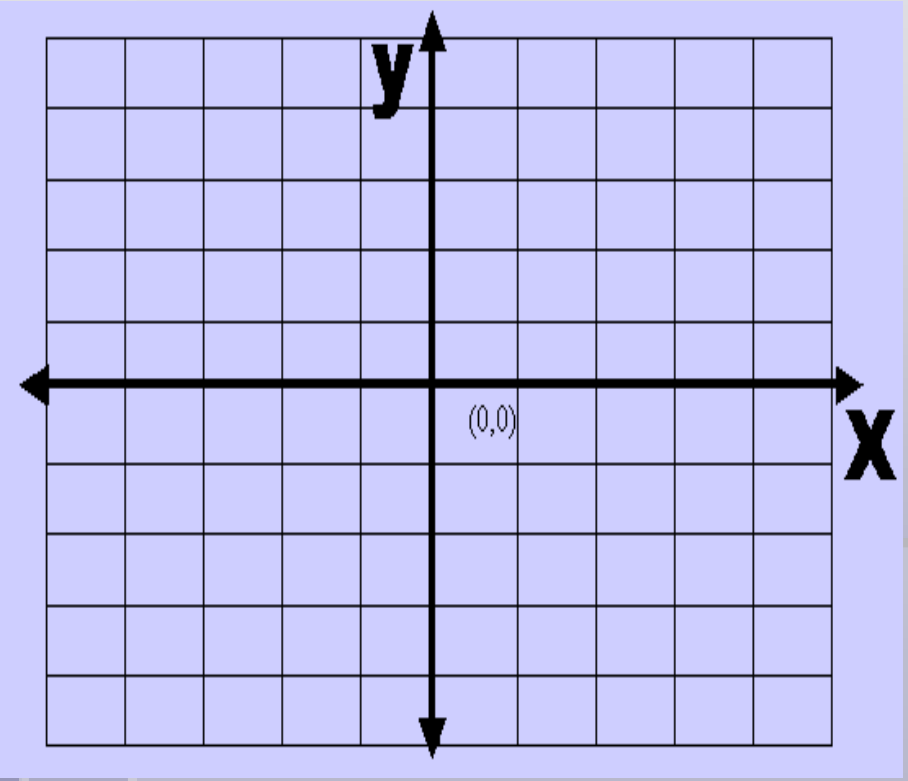
Deep Brain Stimulator

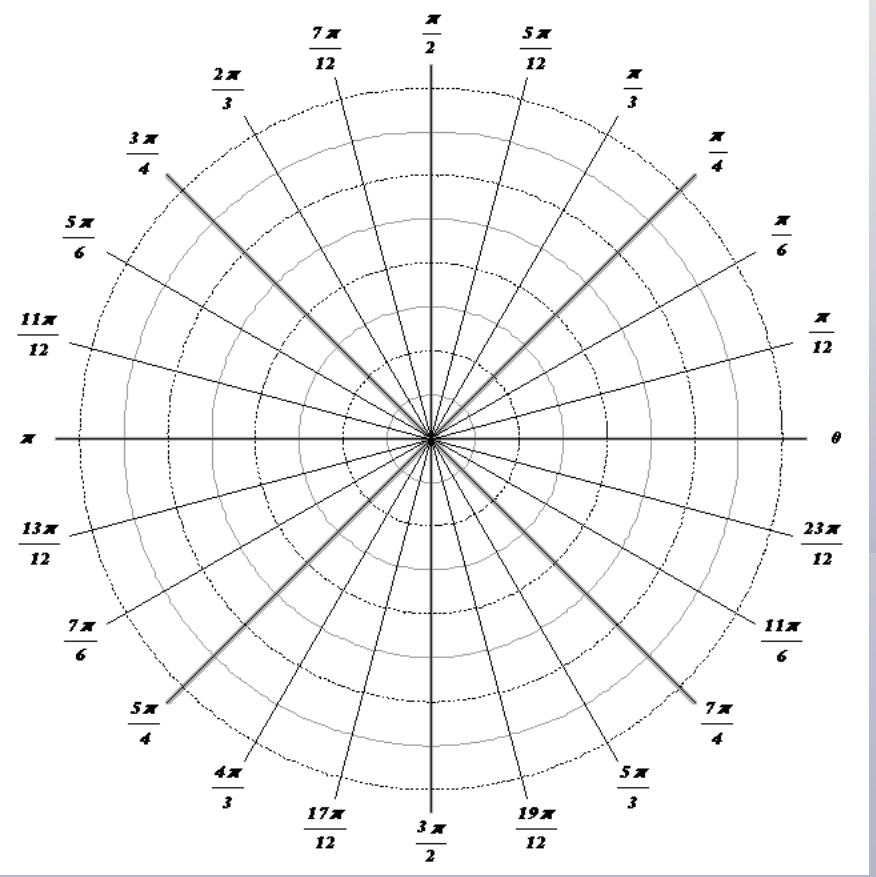




You are familiar with plotting with a rectangular coordinate system.

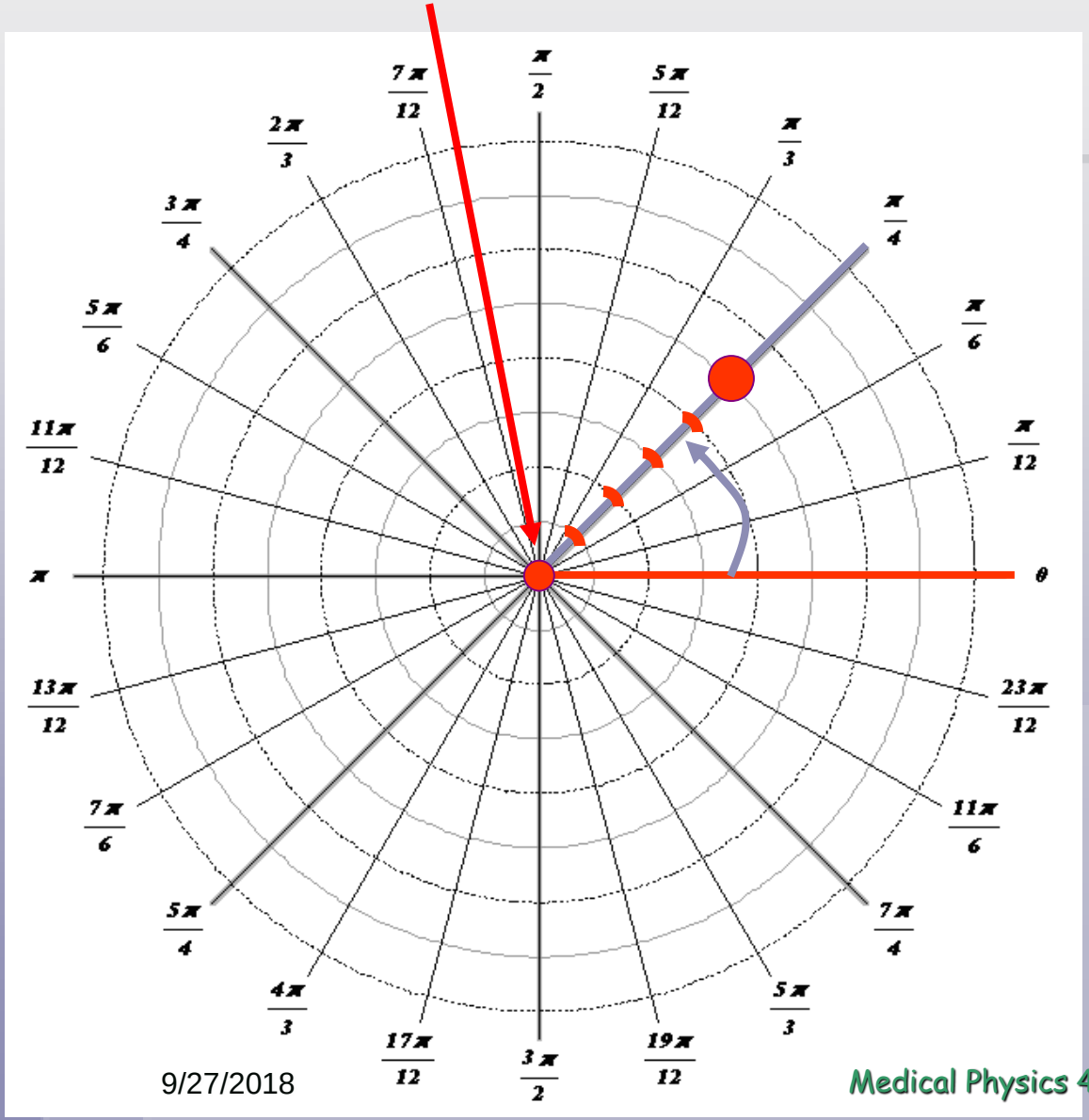
We are going to look at a new coordinate system called the polar coordinate system.





The center of the graph is called the pole.

Angles are measured from the positive *x* axis.



Points are represented by a radius and an angle

radius **angle**

$$(r, \theta)$$

To plot the point

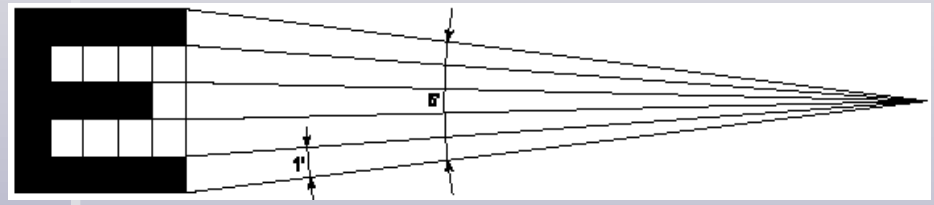
$$\left(5, \frac{\pi}{4}\right)$$

First find the angle

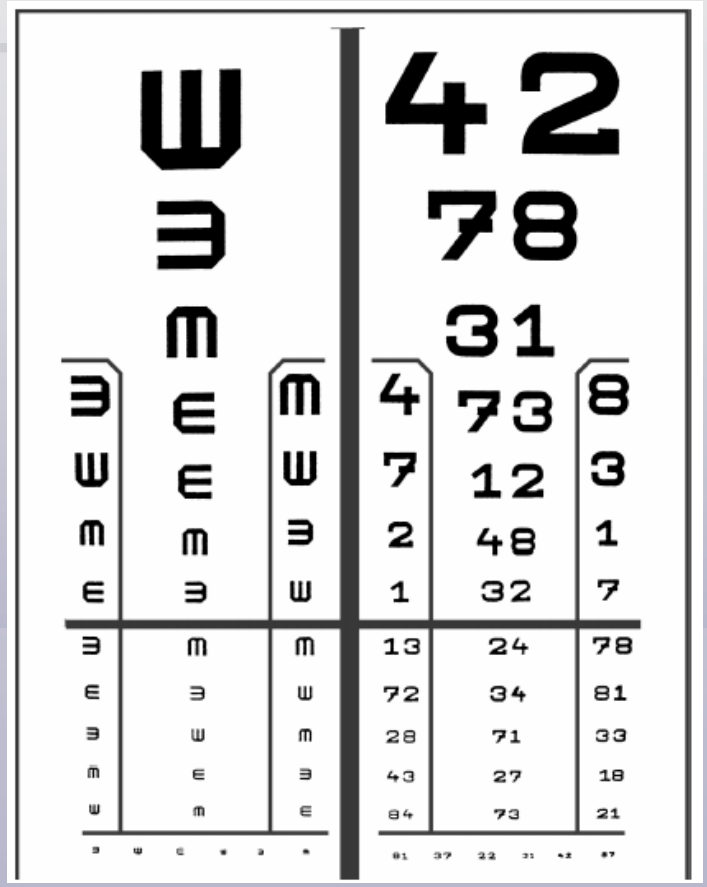
Then move out along the terminal side 5

Determination of visual acuity

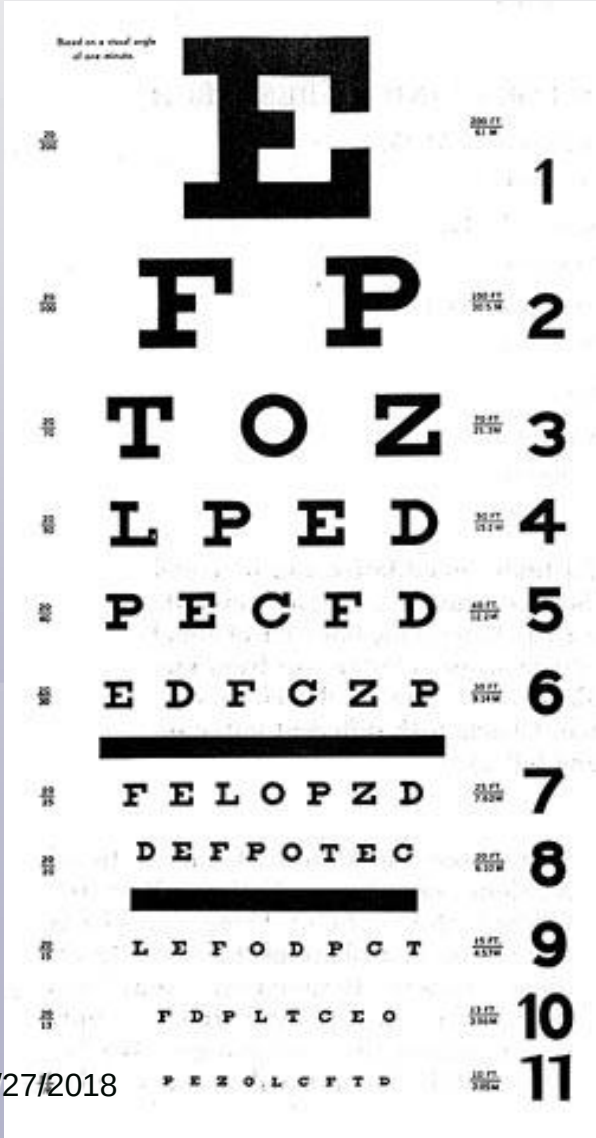
Visus (eye) chart



The biggest letters from 50 m,
The smalles from 5 m 1’ angle



Snellen eye chart



Rosenbaum pocket chart