New Ideas. New Materials.

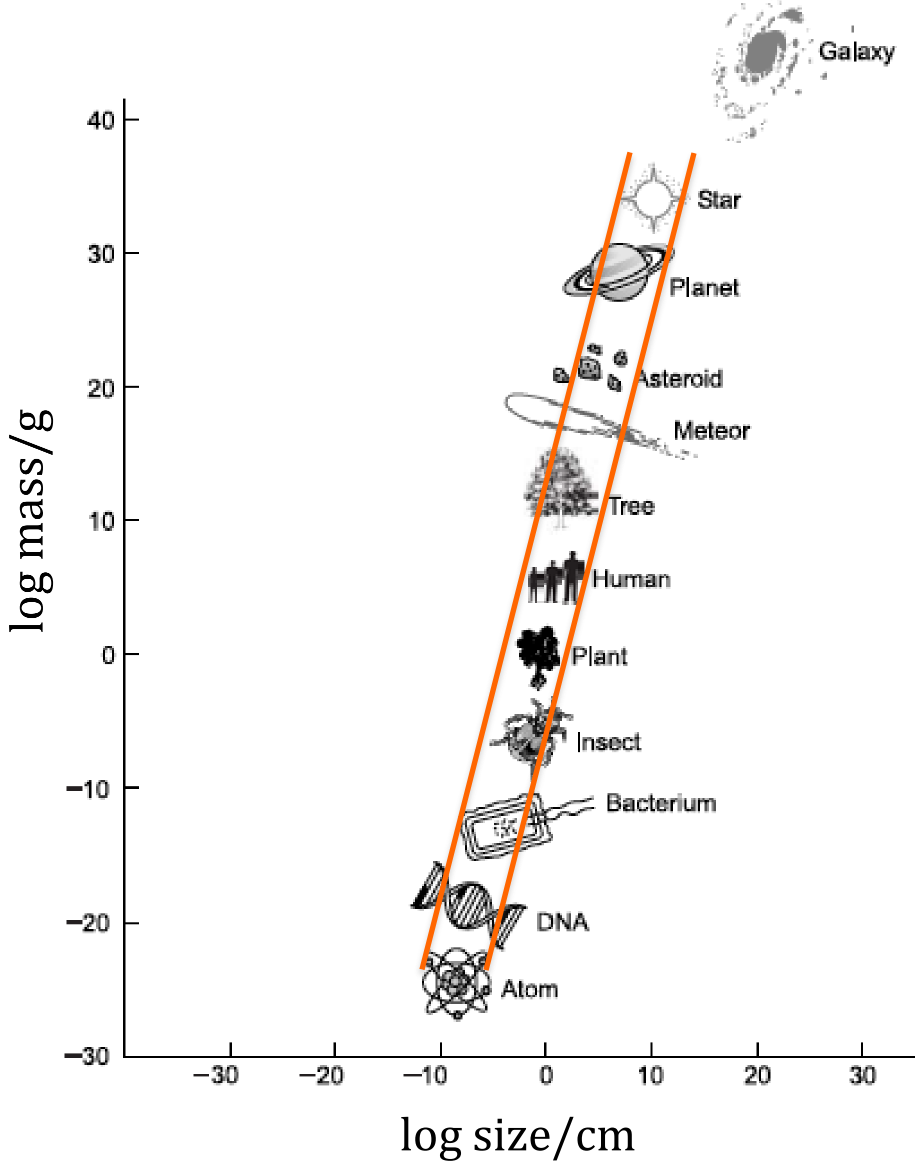
INM

NANOBIOMATERIALS 1
AN INTRODUCTION TO SIZE EFFECTS

Prof. Dr. Eduard Arzt und MitarbeiterInnen
MWWT, Neue Materialien, und INM – Leibniz-Institut für Neue Materialien

SIZE – THE GRAND PICTURE

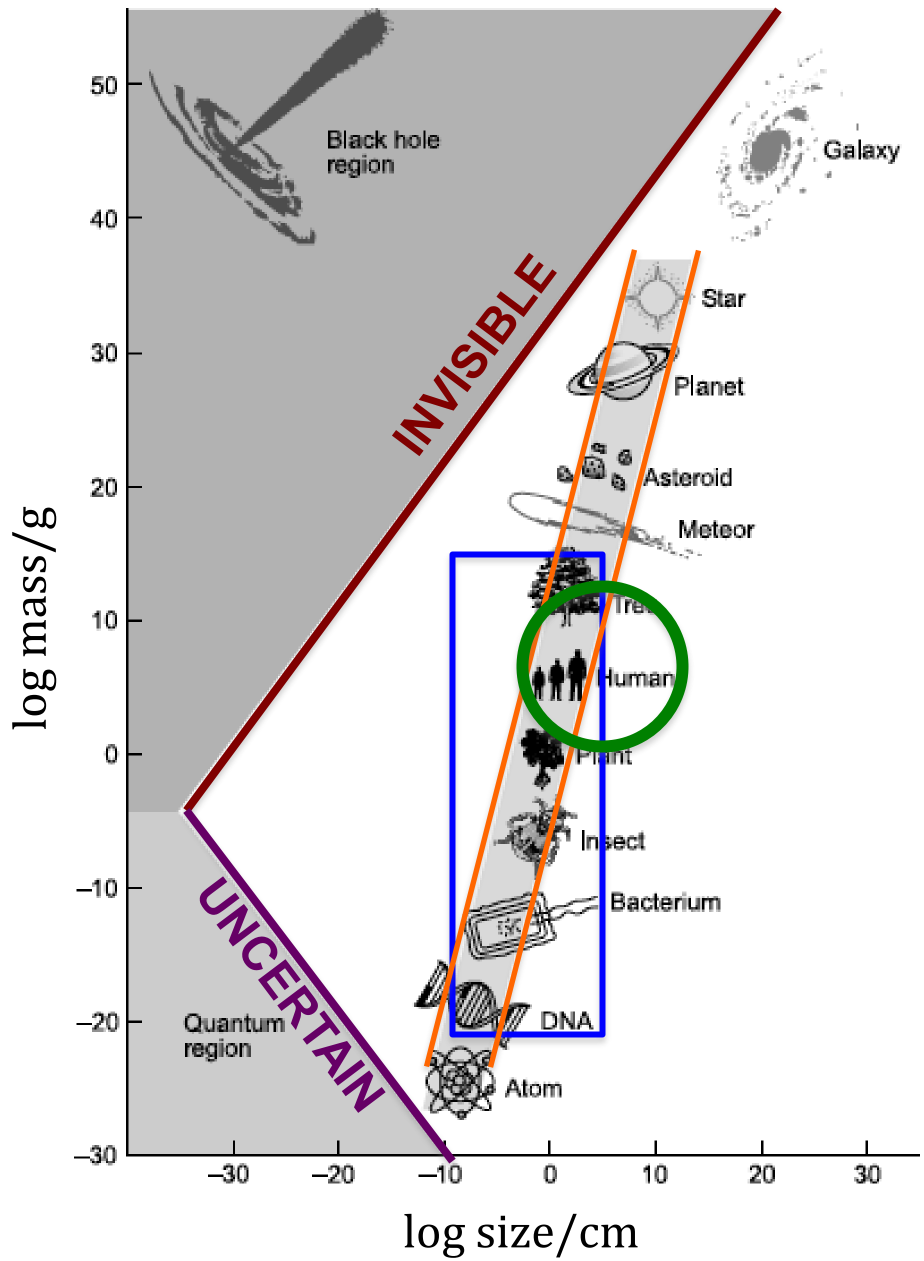
INM



mass vs. size of known objects in the universe

balance between opposing forces of Nature:
gravitation ←→ atomic
(resist crushing by grav. forces)
-> **allowed density range**

from J.D. Barrow,
The Artful Universe Expanded



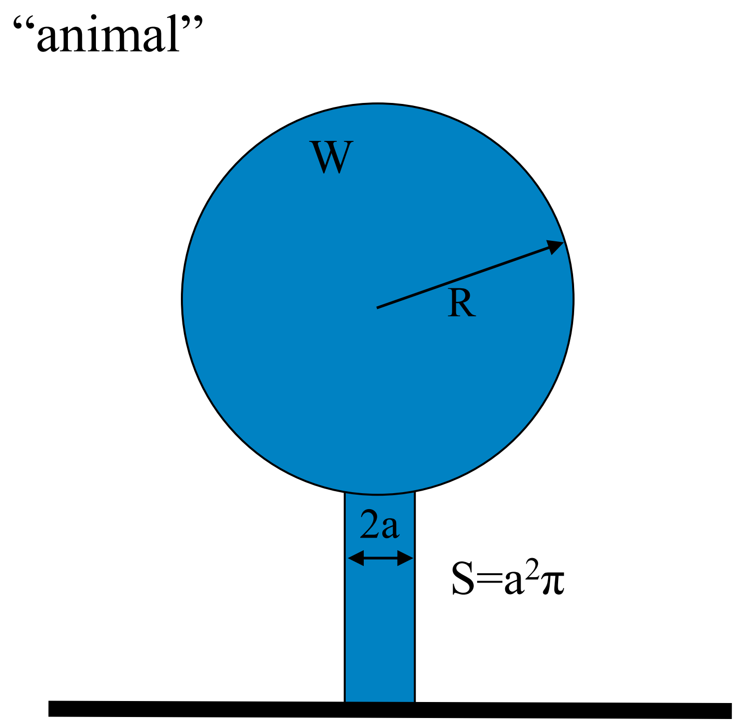
"complex range":
10^{-10} to 10^{5} cm

materials:
10^{-7} to 10^{3} cm

human size!

from J.D. Barrow,
The Artful Universe Expanded

BIG ANIMALS BREAK DOWN



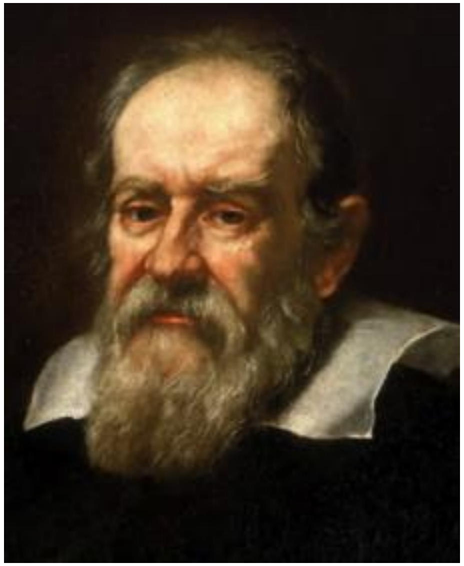
stress calculation

$$weight \sim g(size)^3$$

$$legsection \sim (size)^2$$

$$> stress \sim size.g$$

g..gravitational acceleration



Galileo Galilei
(1564-1642)

- animal size limited by gravitational effects?
- largest dinosaur (*Apatosaurus*): 85 tons
- example for surface/volume effect

SIZE EFFECTS IN MAMMALS

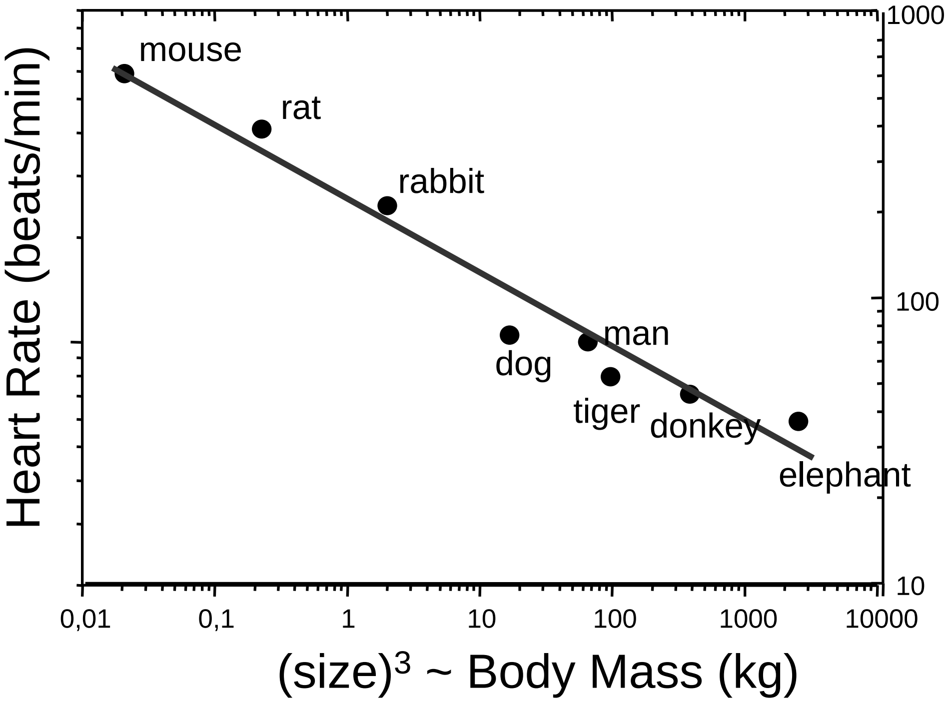
heat balance

$$+\dot{Q} \sim f_{Hz}\,(size)^3$$

$$-\ \dot{Q} \sim (size)^2$$

$$-> f_{Hz} \sim 1/(size)$$

Q...heat supplied
f_{Hz}...heart beat rate



for a detailed derivation see H. Lin, Am J Phys 50, 72 (1982), T. McMahon, Science 179, 1209 (1973)

BIGGER MAMMALS LIVE LONGER

heat balance

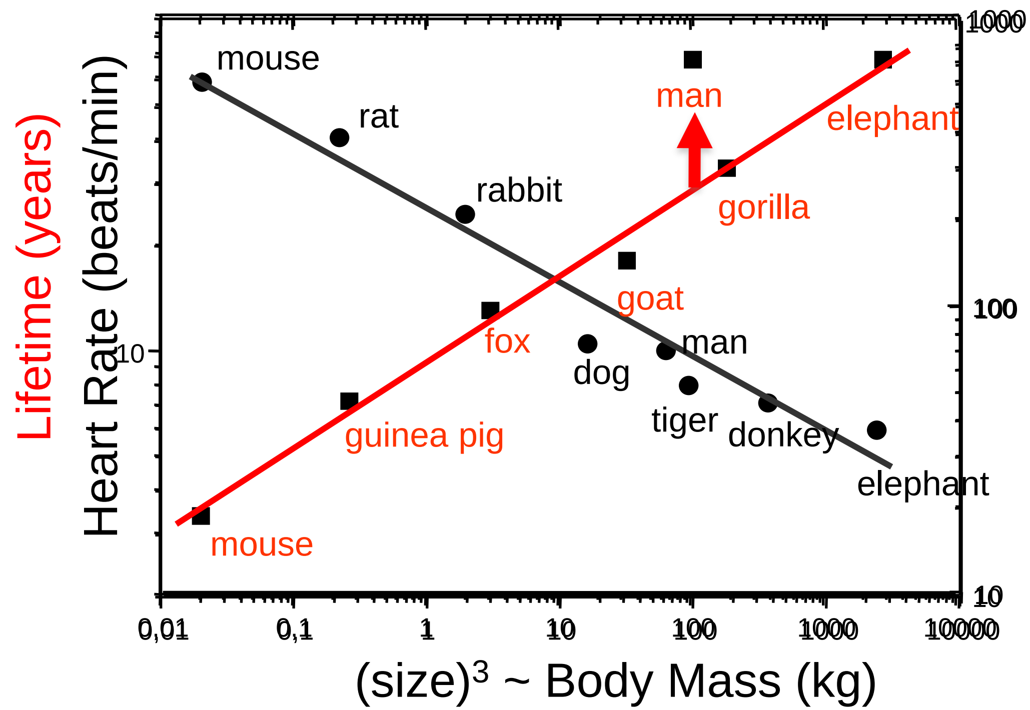
$$+\dot{Q} \sim f_{Hz}\,(size)^3$$

$$-\ \dot{Q} \sim (size)^2$$

$$-> f_{Hz} \sim 1/(size)$$

$$life \sim 1/f_{Hz} \sim size$$

Q…heat supplied
f_{Hz}…heart beat rate



for a detailed derivation see H. Lin, Am J Phys 50, 72 (1982), T. McMahon, Science 179, 1209 (1973)

LARGE OBJECTS FLY FAST

force balance

weight (volume)

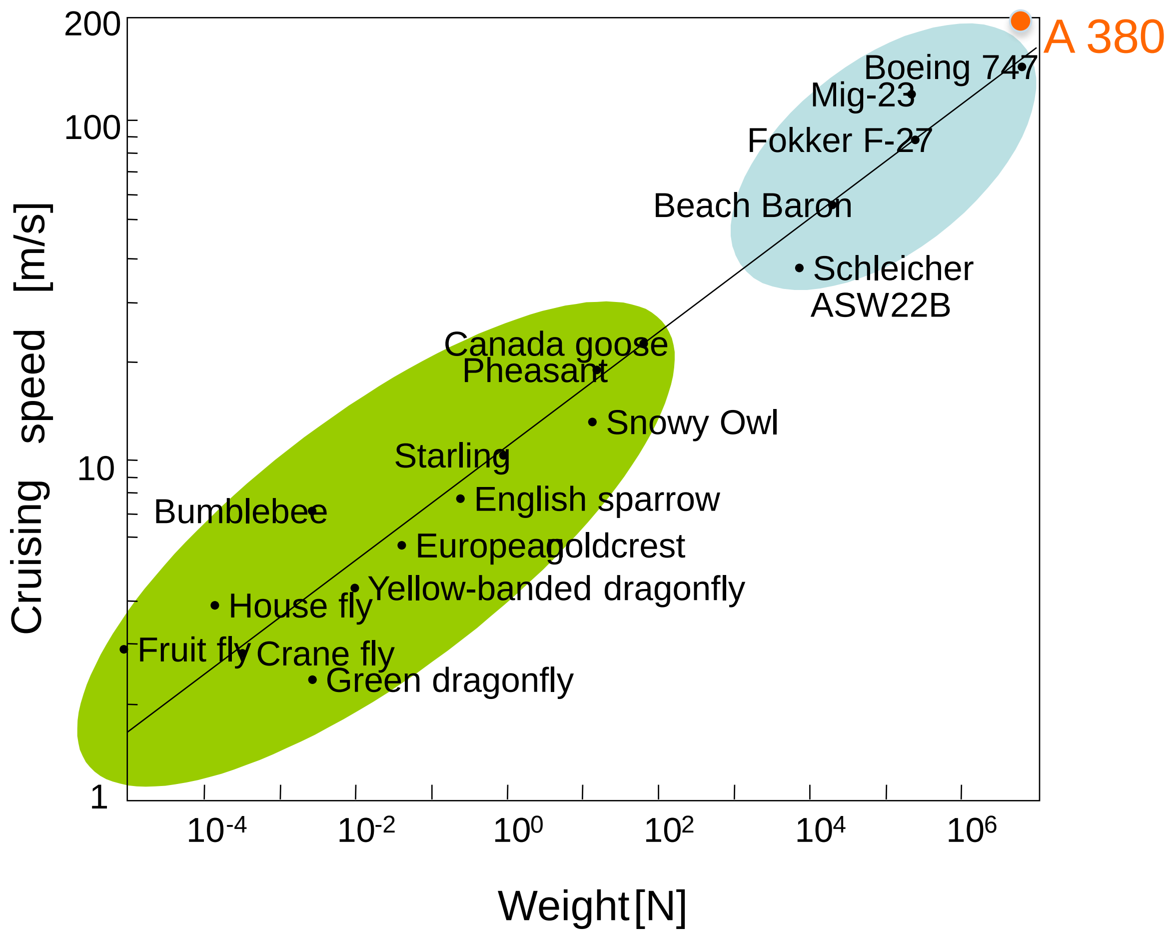
$W \mu R^3$

lift (wing area)

$L \mu V^2 R^2 r$

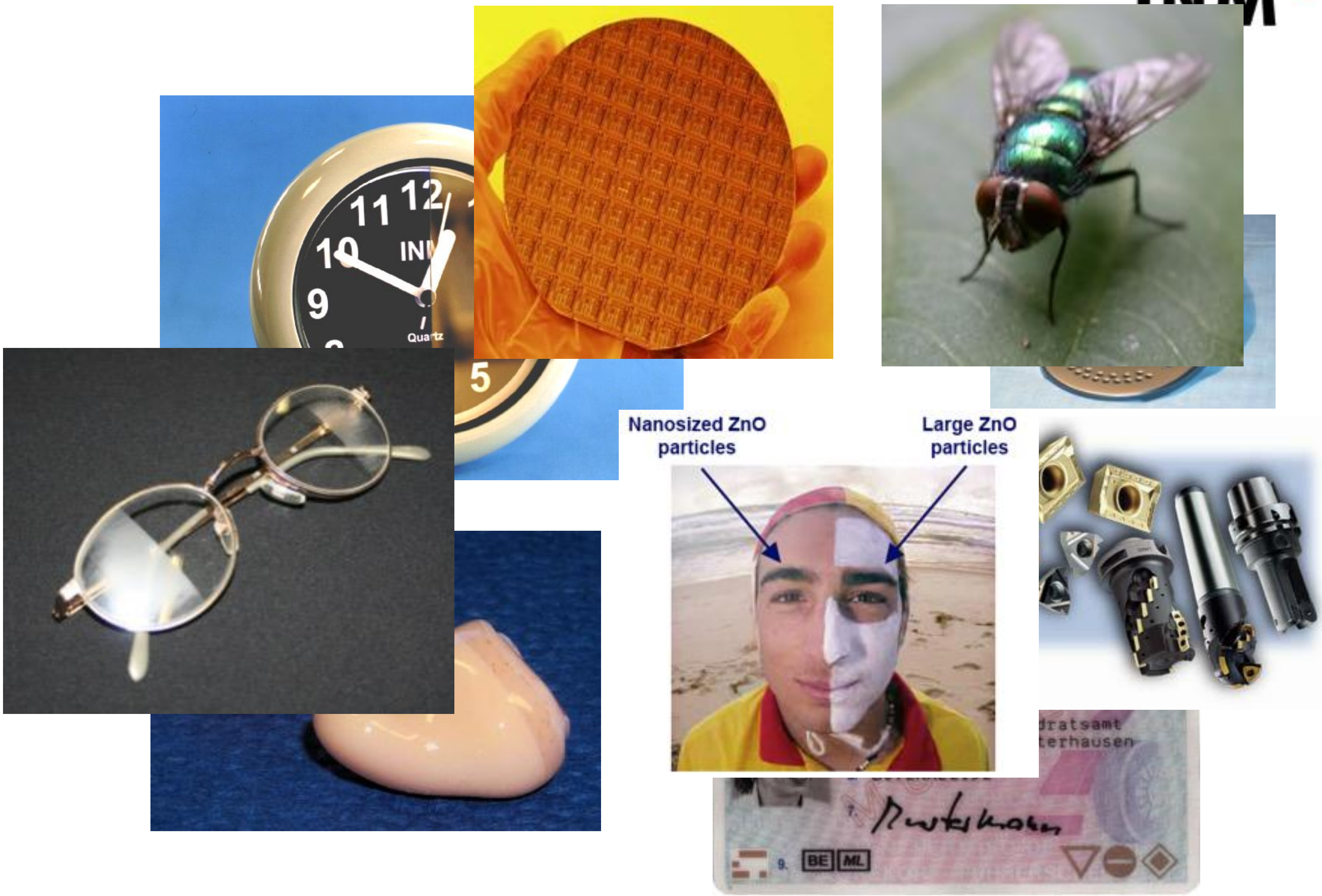
cruising speed

$V \mu W^{1/6} \mu R^{1/2}$

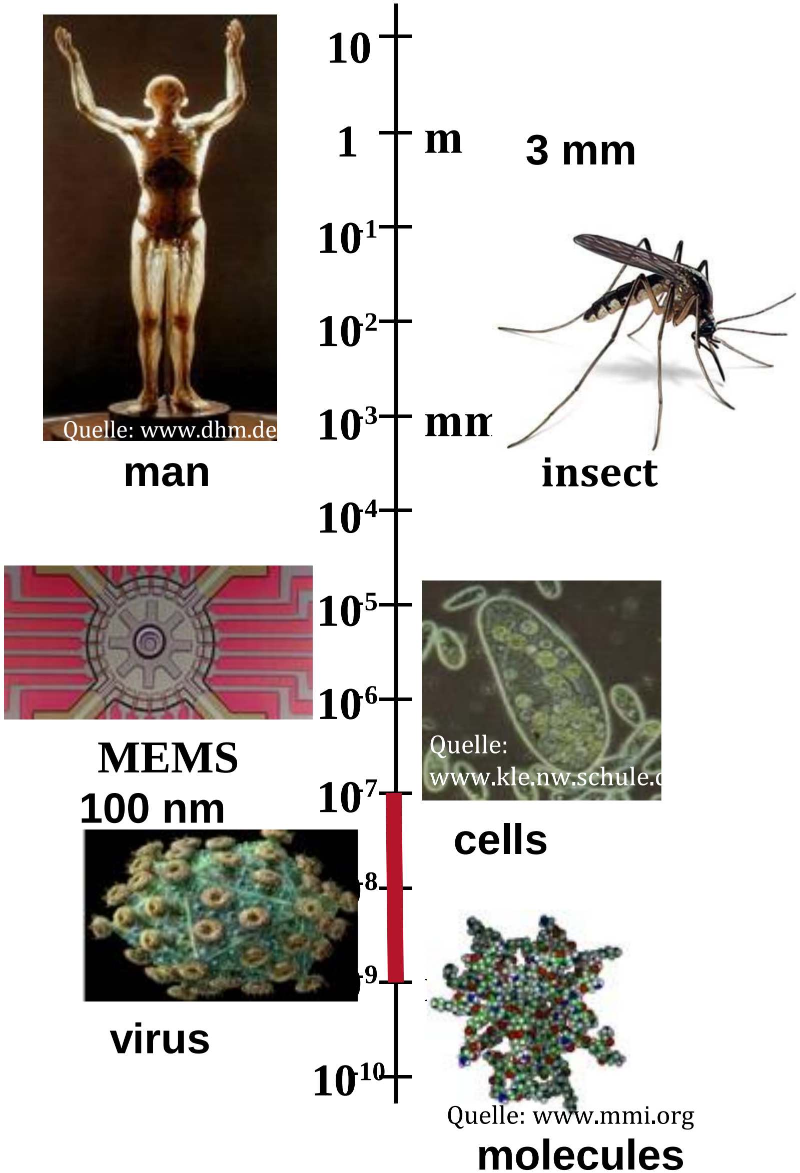


H. Tennekes, The simple science of flight, MIT Press, Cambridge, USA, 1998

NANO IN EVERYDAY LIFE



Definition of „nano“



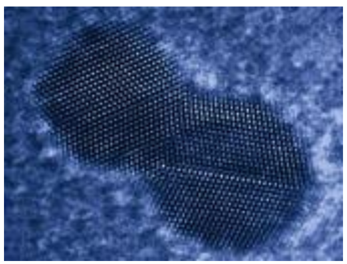
„**nano**“ von griech. „**Zwerg**“

1 Nanometer = 1/1.000.000 mm

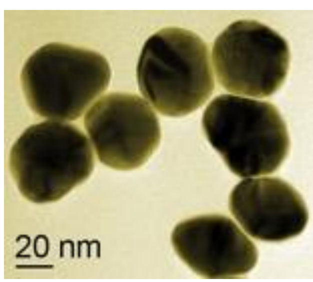
Nanobereich: ca. 1 - 100 nm

NANOMATERIAL ist *„ein natürliches, bei Prozessen anfallendes oder hergestelltes Material, das Partikel in ungebundenem Zustand, als Aggregat oder Agglomerat enthält, und bei dem mindestens 50% der Partikel in der Anzahlgrößenverteilung ein oder mehrere Außenmaße im Bereich von 1 nm bis 100 nm haben.“* (EC, 18.10.11)

NANOMATERIALS

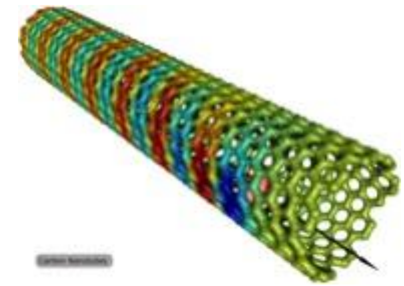


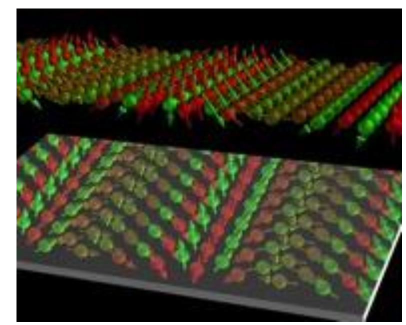
nanoparticles



- nanomaterials
  - nano-object
    - nanoparticle
    - nanotube, -wire
    - nanolayers
  - nanostructured material
    - nanocomposite
    - nanostructured surface
    - nanocrystalline material

nanotubes

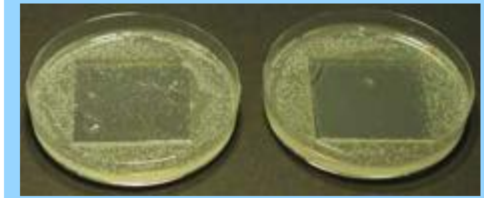




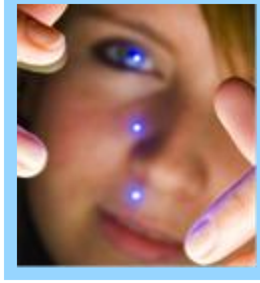
nanolayers

NANOPARTICLES IN APPLICATIONS

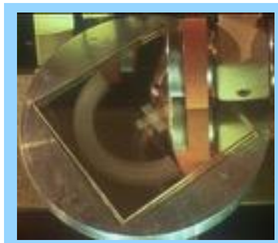
scratch resistance



anti-microbial surfaces



transparent conductive layers



wear resistance

examples:
SiO_2, ZrO_2, TiO_2, CeO_2, ITO, γ-Fe_2O_3, Ag, MoS_2, C, Ag

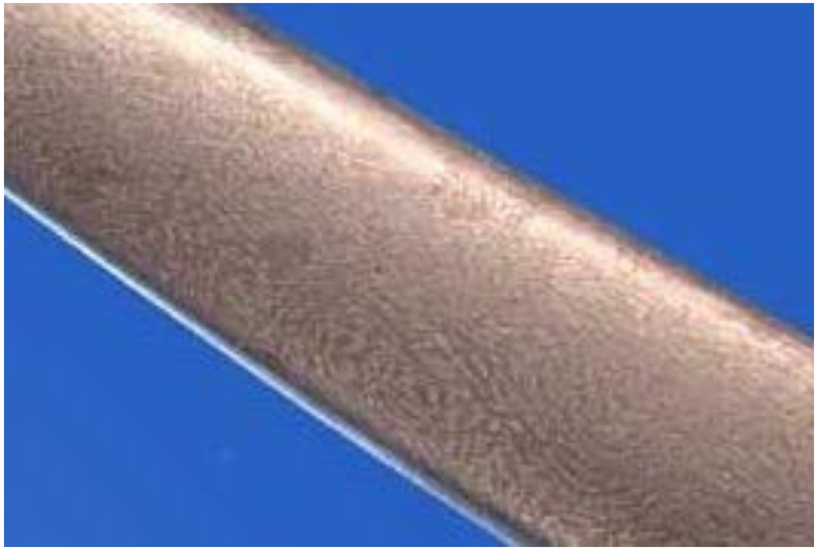
tailored refractive index

corrosion protection

light management

magnetic polymer composites

NANO IN THE DARK AGES



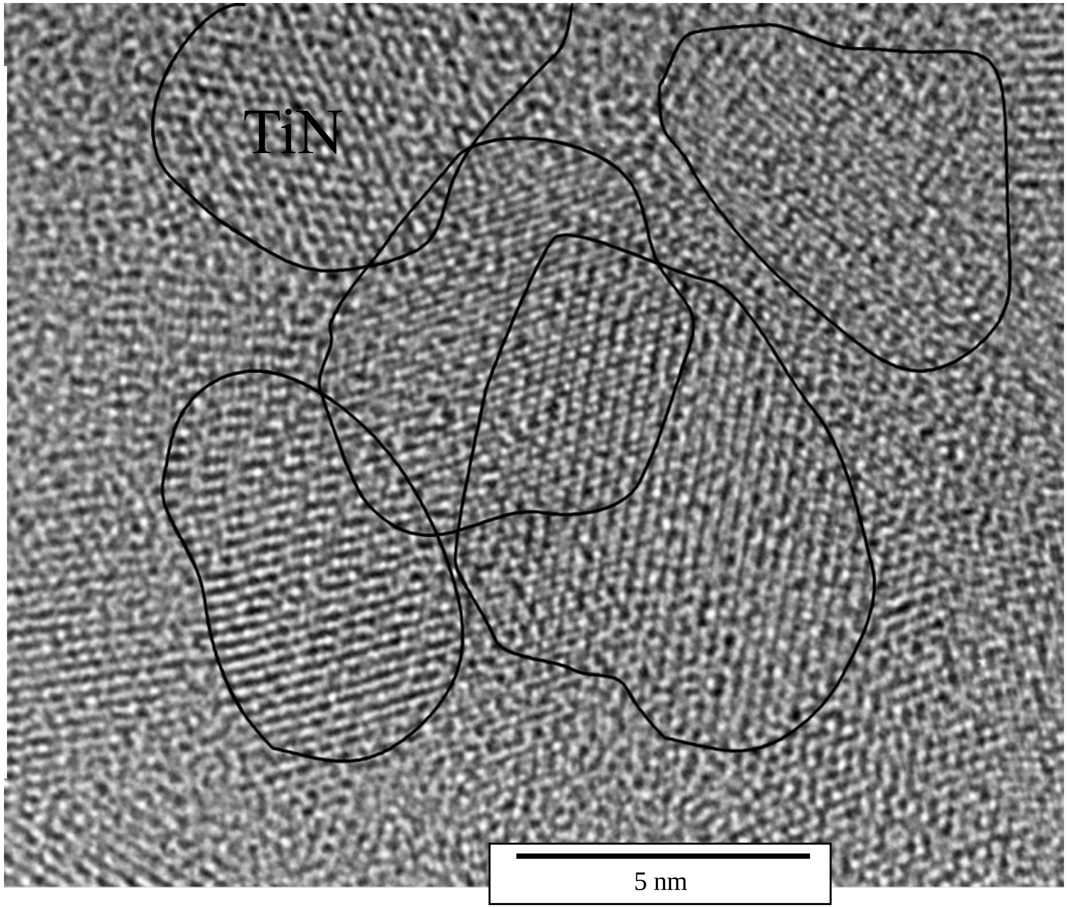
„Damscene steel“
Wieland der Schmied (Mimung)

SMALL IS STRONG!

stained-glass windows with Au particles (Freiburger Münster)

TYPICAL NANOCOMPOSITES

ARM 1250 kV



small (nano)crystals have high strength!

SIZE EFFECTS IN MATERIALS: TYPES

1. surface/ volume

→ scaling effects

→ curvature effects

nanochemistry/ nanomechanics

new batteries
adhesion devices
nanofilters
cosmetics, lacquers

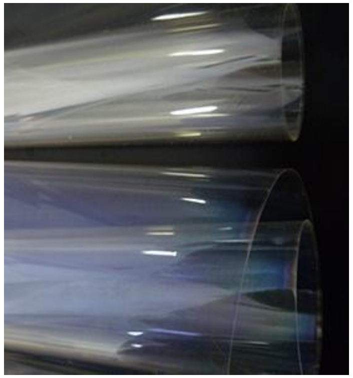
2. size matching

→ light interaction (λ)

→ free mean path(e,ph)

nano-optics

light management
anti-reflection
new lenses
heat insulation
electrosorption



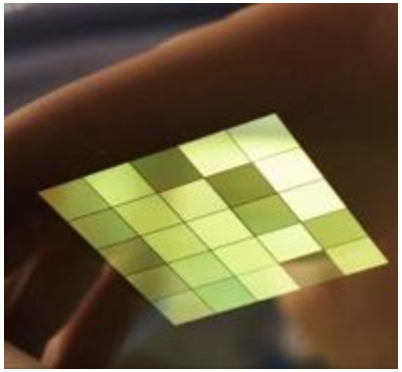
3. quantum effects

→ emission/absorption

→ band gap engineering

nanoelectronics

efficient lighting
new memories
better solar cells
new magnets
self-cleaning



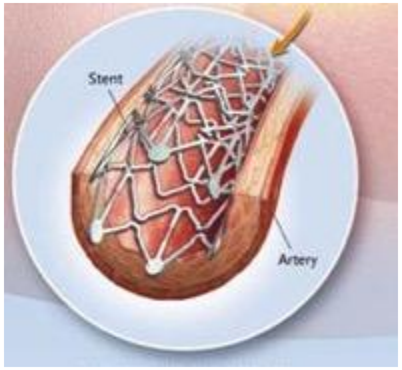
4. bio interaction

→ cell behavior

→ medical surfaces

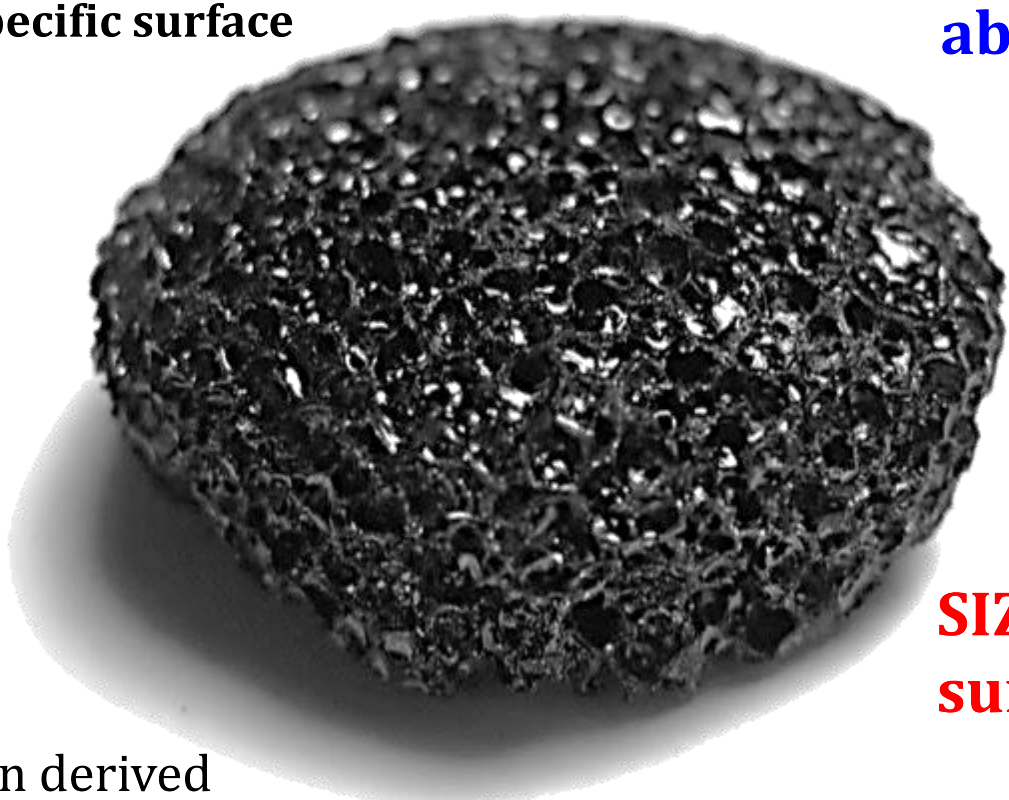
nano-bio

implant engineering
diagnostics
cancer therapy
nanotoxicity
sustainability



ENERGY STORAGE : SUPERCAP ELECTRODES

electric energy storage by electrosorption of ions: Capacitance ~ ions adsorbed per volume: specific surface



porous carbon derived from Si-O-C foam
pore sizes 1nm – 100 µm

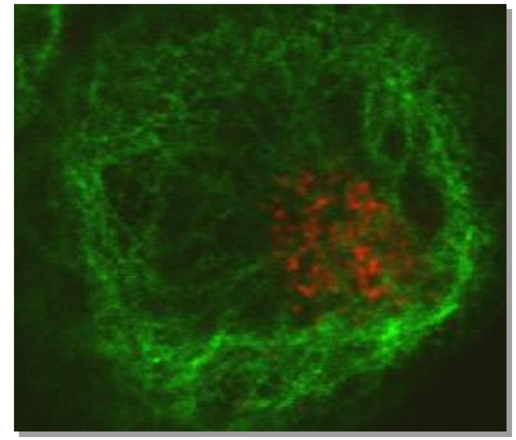
SIZE EFFECT 2: absolute pore size = ca. size of electrolyte ion

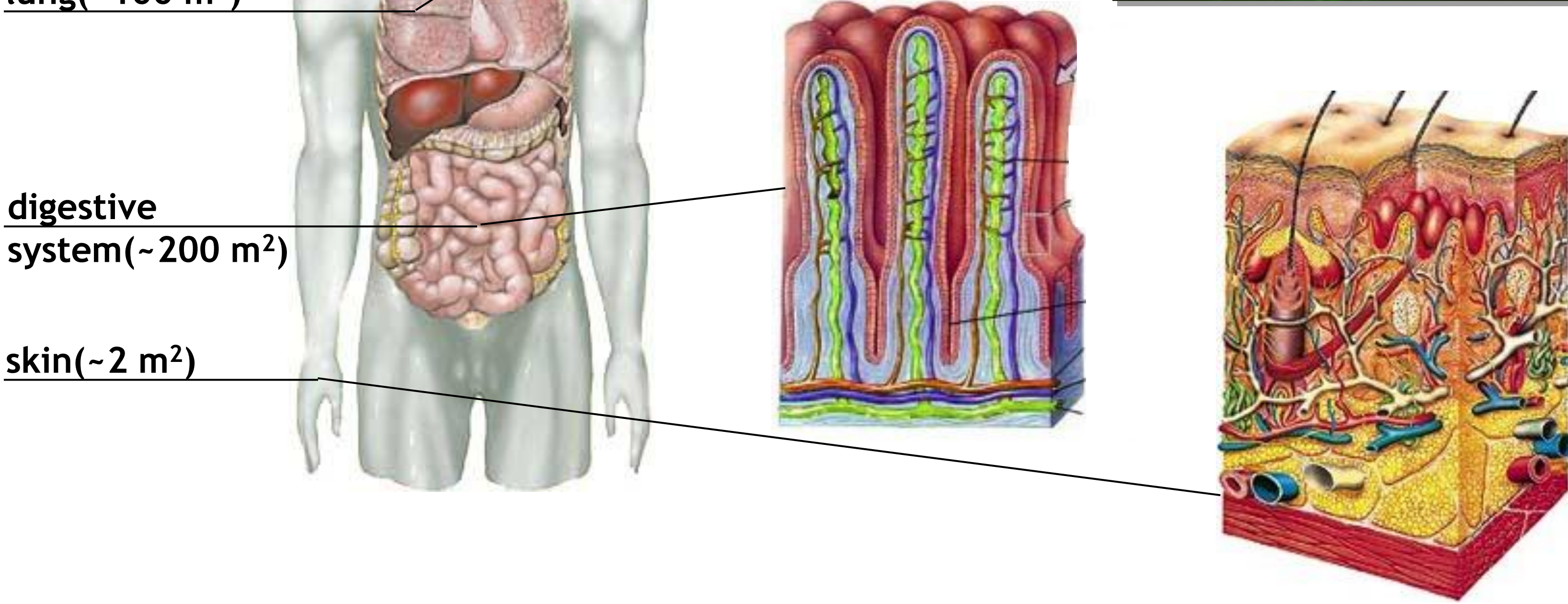
SIZE EFFECT 1: surface/volume ~ 1 / charact. size

V. Presser, INM

POTENTIAL HAZARDS DUE TO NANO-OBJECTS

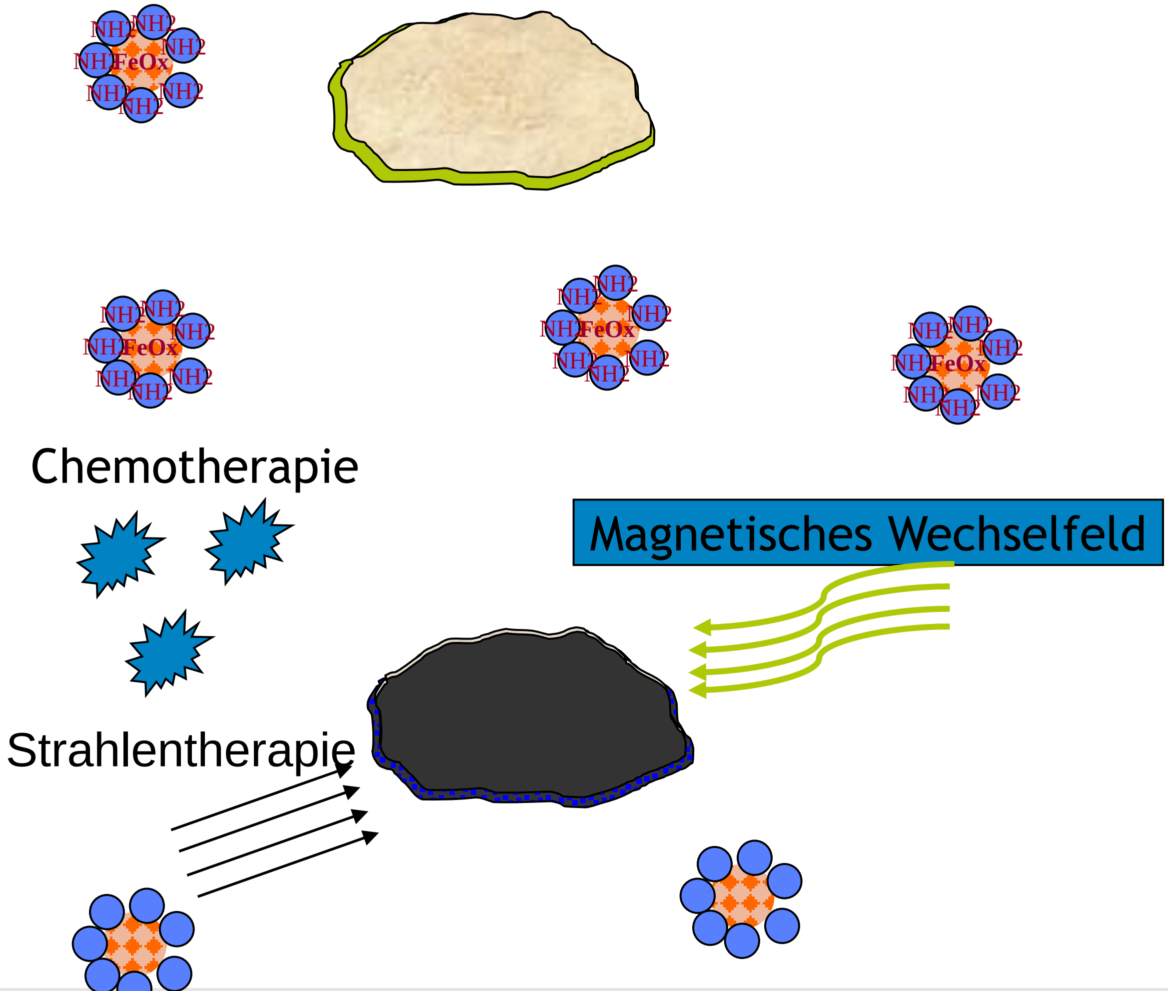
see A. Kraegeloh





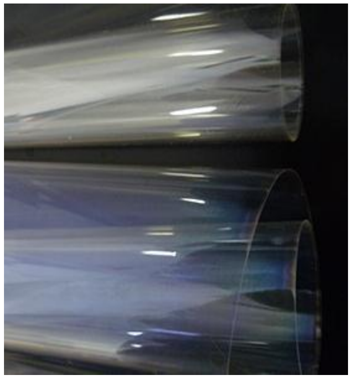
NANOPARTICLES IN CANCER THERAPY

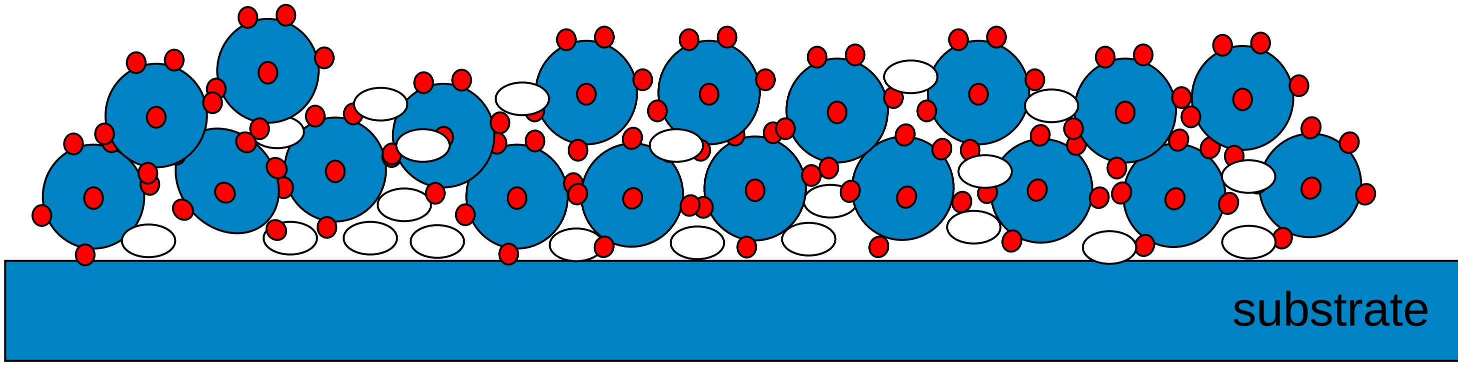
principle



- Injektion der Partikel in Tumor
- Aufnahme der Partikel in die Tumorzellen
- Tumorgewebe wird auf 41-45°C erwärmt
- Die Tumorzellen sind jetzt sensibilisiert.
- Tumorzellen werden per Chemo- / Radiotherapie abgetötet

LIGHT MANAGEMENT / ANTIREFLECTIVE





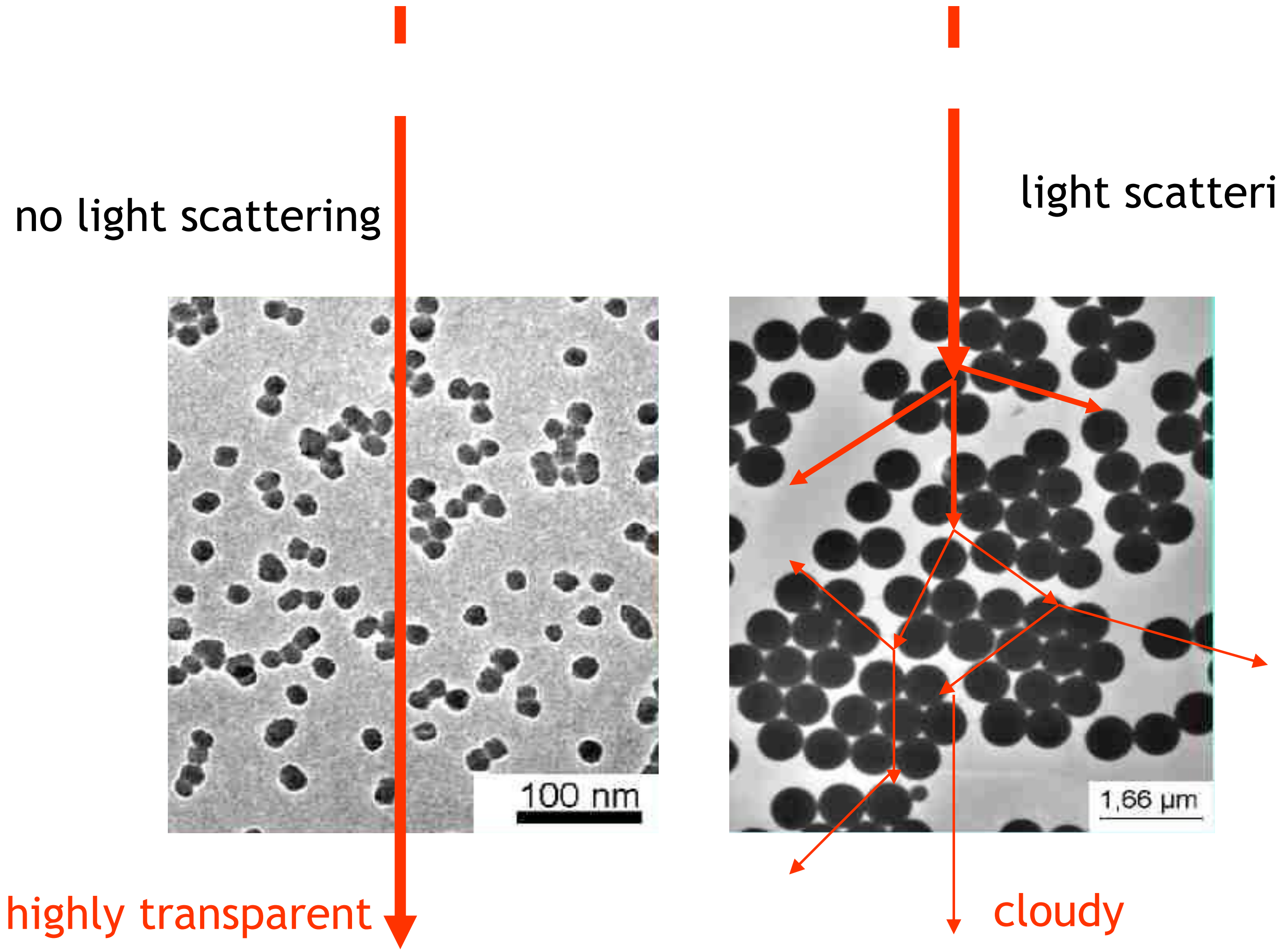
TiO_2 crystallite: 2-7 nm (PHOTOCATALYTIC)

SiO_2 amorphous: 30-50 nm (SCRATCH-RES.)

Pore, void: different sizes (INDEX MATCH)

P. de Oliveira, INM

HIGH TRANSPARENCY VIA SMALL PARTICLE SIZE



C. Becker-Willinger

NANOPARTICLES CAN MODIFY OPTICAL PROPERTIES

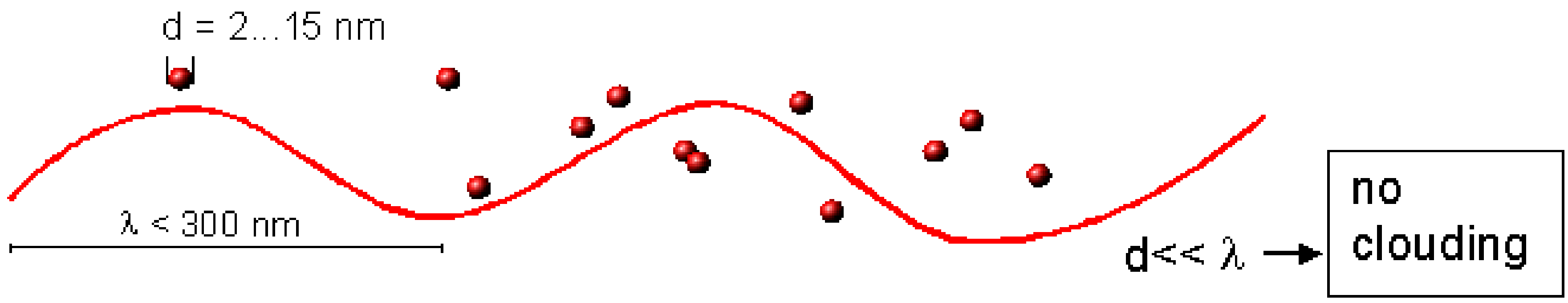
$$n = n_1(1 - c) + n_2 c$$

n ... refractive index of composite
n_1...refractive index of matrix
n_2...refractive index of particle
c....vol% particles

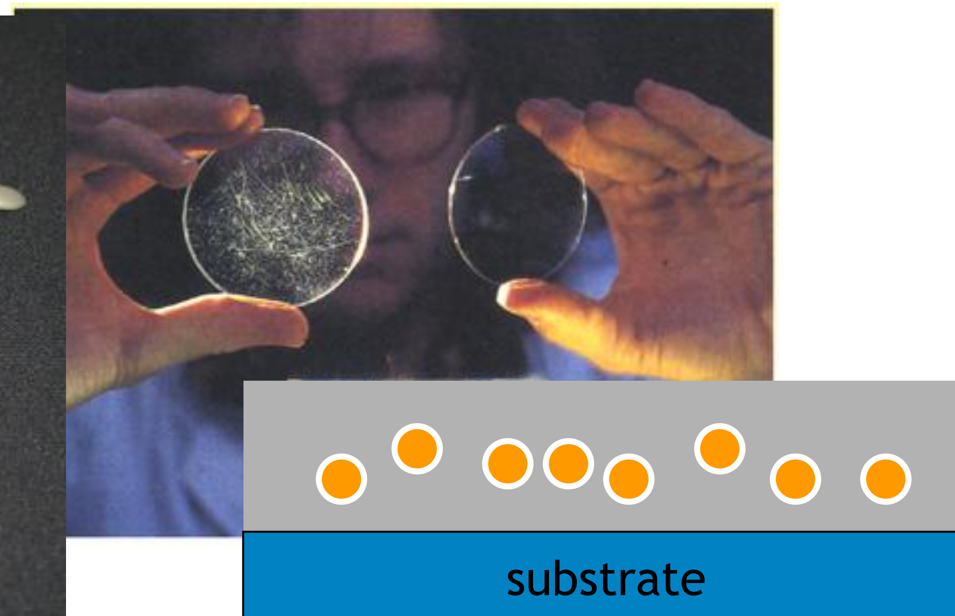
$$\frac{I_{sc}}{I_0} \propto c \frac{D^6}{\lambda^4} \frac{n_2 - n_1}{n_1^2}$$

I_{sc}...scattered intensity
I_o...initial intensity
D...particle diameter
λ...wavelength (λ_0/n_1)

transparency: $D_{max} < 0.05\ \lambda$ (ca. 20 nm), no clusters



SCRATCH RESISTANT *AND* TRANSPARENT



Nanomer® coating for plastic lenses

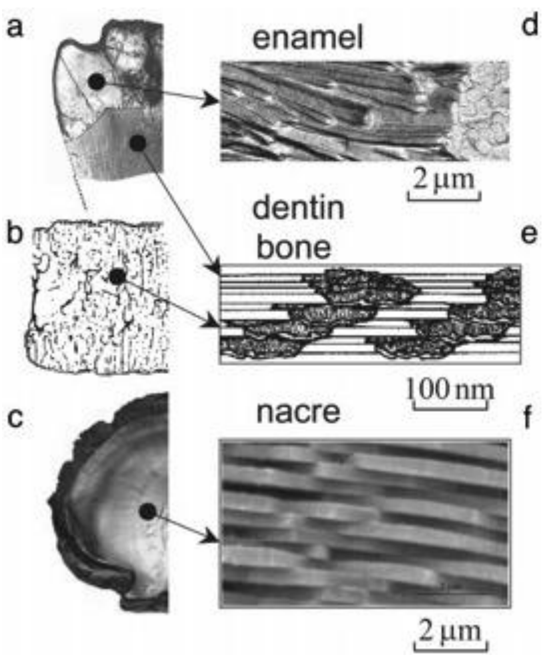
EU driver license

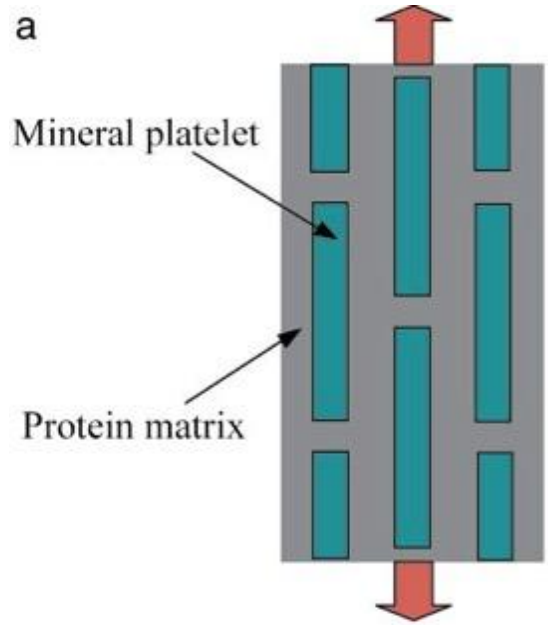
Quelle: www.kba.de

C. Becker-Willinger, INM

ELASTICITY, STRENGTH AND FRACTURE: SMALL = STRONG!

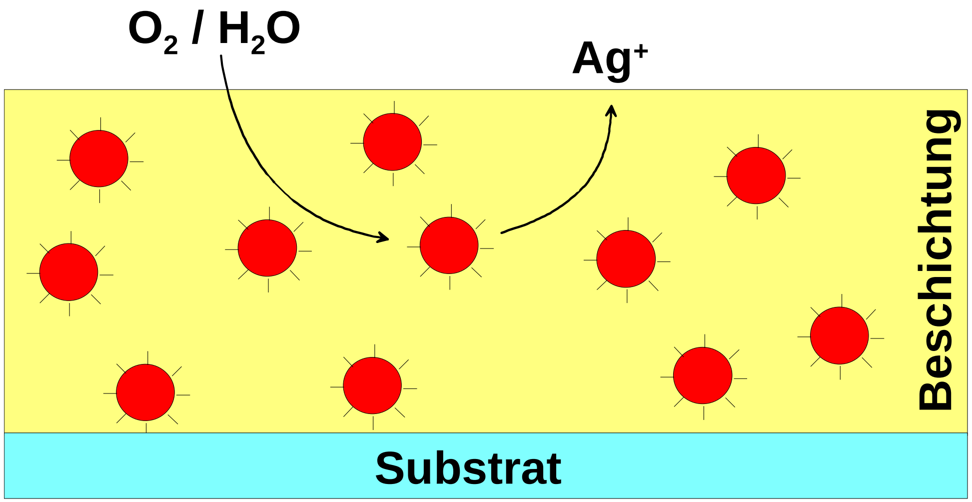
ELASTICITY: no size effect (property of the bond)
PLASTICITY: smaller objects are stronger (plastic deformation impeded)
FRACTURE: small fail later (only small cracks allowed)

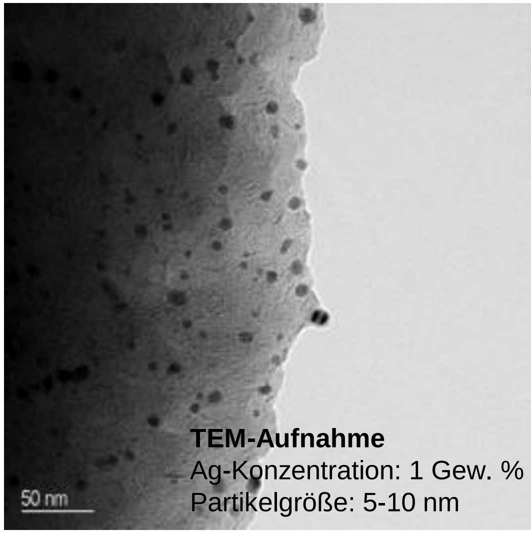




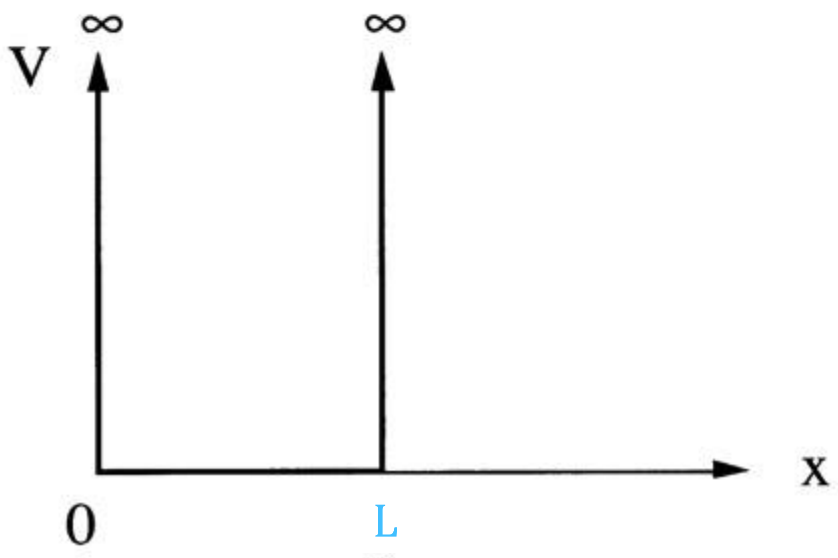
ANTIBACTERIAL SURFACES

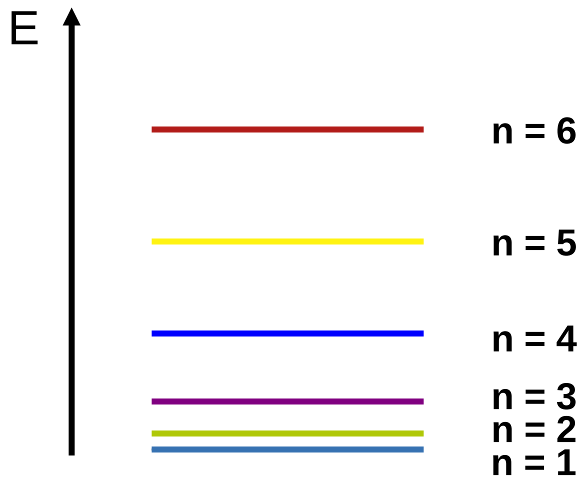
Ag$^+$ ions kill cells: form in presence of water





REMINDER: QUANTUM CONFINEMENT OF ELECTRON IN INFINITE WELL





energy quantisation

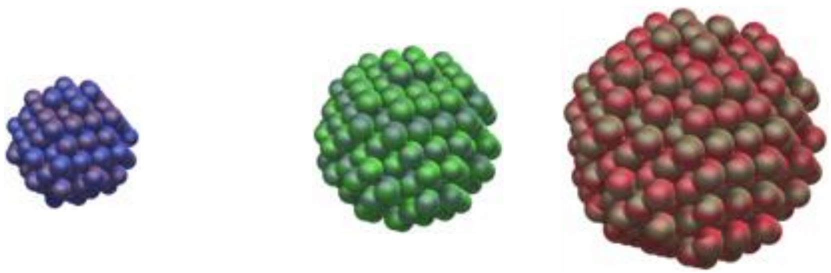
$$E_n = \frac{\hbar^2 p^2}{2mL^2} \times n^2$$

>> small systems have *higher* energy levels and differences between them, therefore transitions are associated with *smaller* wavelength radiation („blue shift“ with smaller size)

COLOR EFFECTS IN NANOPARTICLES

semi-conductors (quantum confinement)

metals (plasmon resonance)



CdSe quantum dots [Niemeyer, 2005]

metallic nanoparticles [Wagner, 2007]

after A. Kraegeloh, INM

SOME TAKE HOME QUESTIONS & MORE

- How is the “nano-range” defined? What are nanomaterials, nanoobjects?
- Which generic kinds of size effects can be distinguished? Examples?
- How does size affect the elastic properties? What is elasticity? Which law governs elastic behavior?
- What is strength? stiffness? toughness?
- How does size affect plastic strength? What is plasticity? Which materials constants are used to describe it?
- *How does size affect fatigue of metals? What is fatigue?*
- *How does size affect the magnetic properties? What is superparamagnetism?*
- Why are most materials in nature nanocomposites? Examples?
- How can nanoparticles affect optical properties? Why are nanoparticles needed to form scratchresistant transparent coating?
- How is an electron affected by a square potential? How does size affect energy levels and transitions between states?
- What is meant by plasmon resonance?
- Why are nanoobjects of interest in biology and medicine?