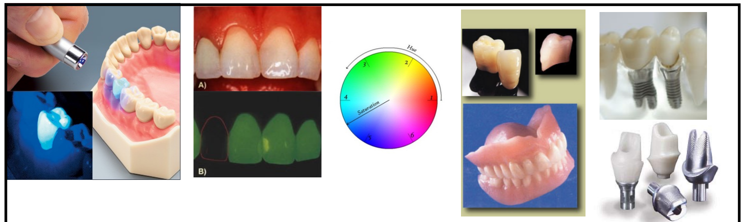


Physical bases of dental materials
11.

Electric properties

Optical properties.

Comparative summary.

e-book chapters: 19, 20, 21

Electric charge

Charge: intrinsic property (like mass).
Macroscopic bodies are usually neutral.

electron (ηλεκτρον) = amber

Electron negative, proton positive charge.

Electric charge is quantizes, its smallest unit is the ***elementary charge (e)***, that is the charge of a proton.
Unit: 1 C (Coulomb) = 1 A·s

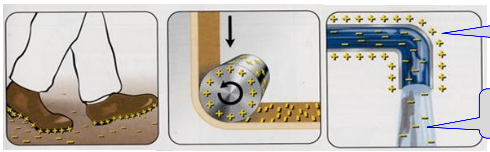
$$e = \left|e^{-}\right| = 1{,}6 \cdot 10^{-19}\,\mathrm{C}$$

Faraday-constant (total charge of 1 mol protons):

$F = 1{,}6 \cdot 10^{-19}\ \mathrm{C} \cdot 6 \cdot 10^{23}\ \mathrm{1/mol} = 96\,500\ \mathrm{C/mol}$

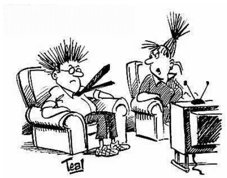
Charge separation

Charges can be separated by rubbing (static electricity)



lack of electrons

electron excess



"I told you nylon carpets were a mistake."

charge separation followed by discharge!

Electric interaction

Bodies with electric charge interact with each other:
- unlike charges attract
- like charges repel

attracting force: F_{21}, F_{12} between Q_1 (−) and Q_2 (+) at distance r

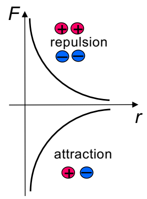
$$F_{12} = F_{21} = F$$

repelling force: F_{21}, F_{12} between Q_1 (−) and Q_2 (−) at distance r

Coulomb-force:

$$F = k\frac{Q_1 Q_2}{r^2}$$

$k = 9 \cdot 10^{9}\ \mathrm{Nm^2/C^2}$



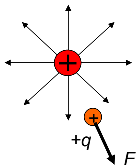
Electric field, filed lines

If the interaction is present without close contact, a field is present that transmits the force between the bodies.

The field is described by the field strength and represented by the field lines.

electric field strength, *E*:

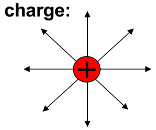
$$E = \frac{F}{q} \qquad \left[\frac{N}{C}\right]$$

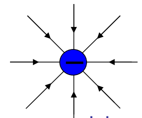


field lines:

- Direction shows the direction of field
- density shows the field strength

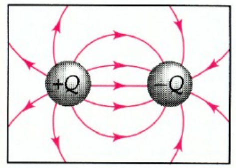
Field of a point charge:

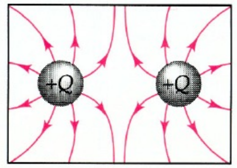




inhomogeneous field

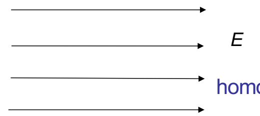
field of a dipole and two like charges





inhomogeneous field

field between the plates of a planar capacitor



homogeneous field

Electric potential

$W_{0\rightarrow i}$ represents the work that is required to move a charge of q from a standard 0 point to point i.

$\frac{W_{0\rightarrow i}}{q}$ independent of charge and path of movement!

Electric potential: $\varphi_i = \frac{W_{0\rightarrow i}}{q}$ Unit: Volt (V)

Electric potential gives the potential energy of the 1 C charge at point i, after it has been moved there from the standard 0 point.

Often the standard point is at infinity, thus:

$$\varphi_i = \frac{W_{\infty\rightarrow i}}{q}$$

Voltage (= potential difference)

The work of $W_{1\rightarrow 2}$ is required to move a q point charge between point 1 and point 2 of the field. The $W_{1\rightarrow 2}$ / q ratio id independent on the magnitude of charge and the path of movement. Thus:

Electric voltage between point 1 and point 2 is:

$$U_{21} = \frac{W_{1\rightarrow 2}}{q}$$ Unit: Volt [V] $$1\,\text{V} = \frac{1\,\text{J}}{1\,\text{C}}$$

Electric current

Directed transport of charge carriers
charge carriers = freely moving , electrically charged particles
example in metals: **electrons**
example in electrolytes or gases: **ions**

Electric current (I):

$$I = \frac{\Delta Q}{\Delta t}$$

ΔQ: charge passing through the cross section of a conductor in Δt time

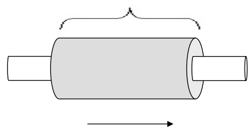
unit: ampere (A), 1A = 1C/1s

Technical current direction: direction of movement of positive charge carriers.

9

Ohm's law

U



I

Potential difference (U) and current (I) are directly proportional

$U \sim I$

$U = RI$ — R: resistance

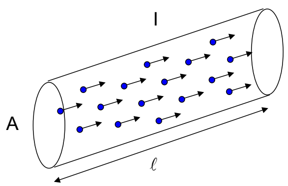
$GU = I$ — G: conductance

$$R = \frac{U}{I} \qquad \text{unit: ohm } (\Omega)\ 1\Omega = \frac{1\text{V}}{1\text{A}}$$

$$G = \frac{1}{R} \qquad \text{unit: siemens (S), } 1\text{S} = \frac{1}{1\Omega}$$

10

Resistance of a conductor



$$\left.\begin{array}{l} I \sim \frac{A}{\ell} U \\ I = \frac{U}{R} \end{array}\right\} R \sim \frac{\ell}{A} \Rightarrow R = \rho \frac{\ell}{A}$$

resistivity
SI-unit: Ωm

conductivity (σ):
SI-unit: S/m

$$\sigma = \frac{1}{\rho}$$

11

- **resistivity**
  or specific resistance (ρ):

$$\rho = \frac{R \cdot A}{l} \quad (\Omega\text{m})$$

- **conductivity (σ):**

$$\sigma = \frac{1}{\rho} \quad ((\Omega\text{m})^{-1} = \text{S/m})$$

material	σ (S/m)	
silver	$6{,}8 \cdot 10^{7}$	conductors
gold	$4{,}3 \cdot 10^{7}$	conductors
platinum	$0{,}94 \cdot 10^{7}$	conductors
germanium	2,2	semi conductors
silicon	$4 \cdot 10^{-4}$	semi conductors
cirkonia	$\approx 10^{-10}$	insulators
porcelain	$\approx 10^{-11}$	insulators
glass	$\approx 10^{-13}$	insulators
PMMA	$\approx 10^{-12}$	insulators
PE	$\approx 10^{-16}$	insulators

Depends on:

-- quantity of free charge carriers (electorns, ions)

-- mobility of charge carriers

12

Electric structure of solid bodies

Bands fill according to:

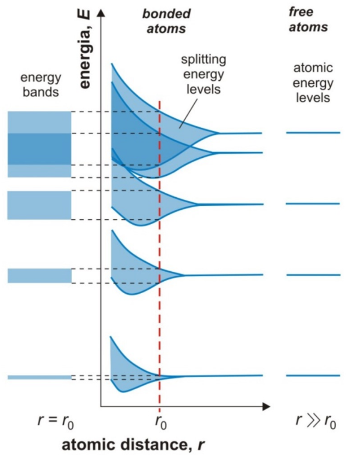
- energy minimum
- Pauli-principle
- number of electrons

- **conduction band**

  Lowest empty or partially filled band

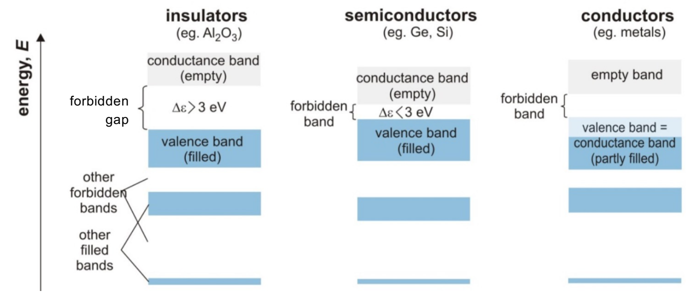
- **valence band:**

  outermost band that his filled with electrons.



13

13



width of forbidden band:

f.e. NaI (Δε = 5 eV)

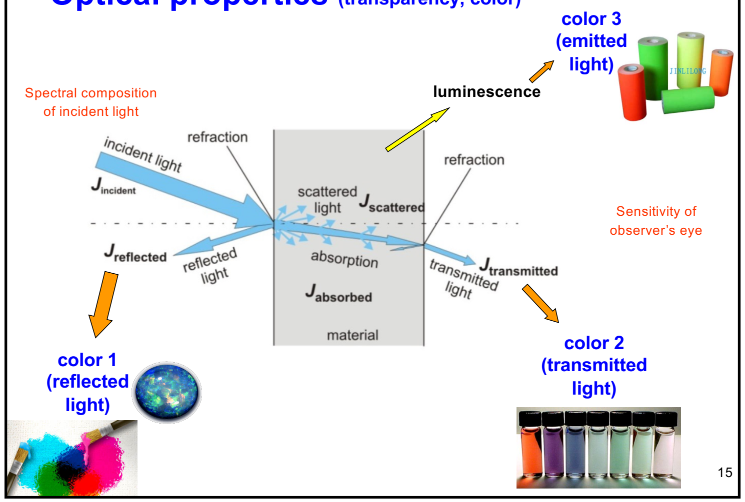
Si (Δε = 1,1 eV)

Ge (Δε = 0,7 eV)

14

14

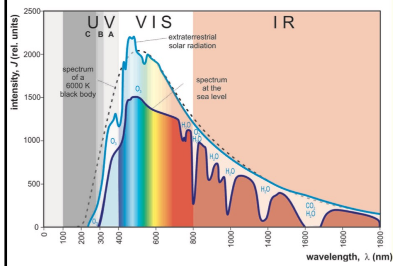
Optical properties (transparency, color)



15

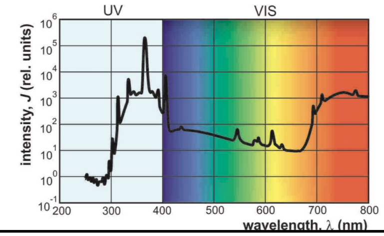
15

Spectral composition of incident light– emission spectrum



natural light – spectrum of Sun

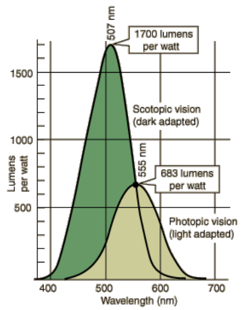
artificial light–
spectrum of a disco lamp

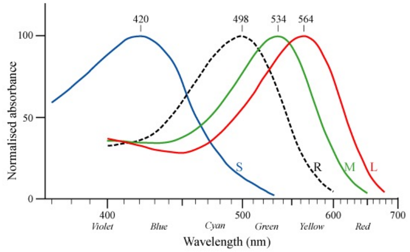


16

16

Spectral sensitivity of the observer — absorption spectrum



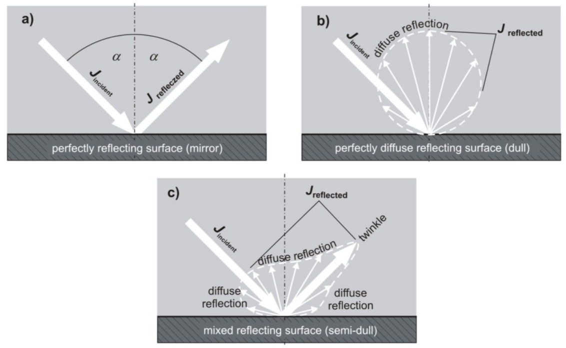


17

17

Interaction of light with matter ⇒ color

1. Reflection:



Spectral reflectance $\rho(\lambda)$**:**

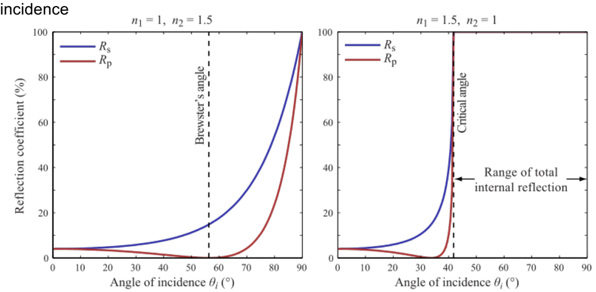
$$\rho_\lambda = \frac{J_{reflected}}{J_{incident}}$$

18

18

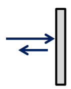
ρ depends on:

- angle of incidence



- type of materials (refractive indeces)

when angle of incidence is zero:



$$\rho = \left(\frac{n_1 - n_2}{n_1 + n_2}\right)^2$$

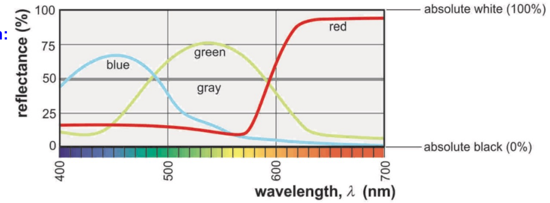
19

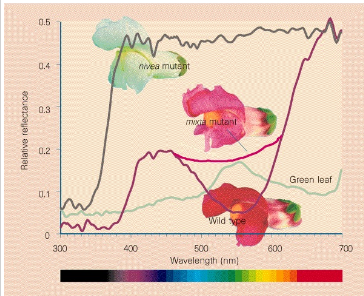
19

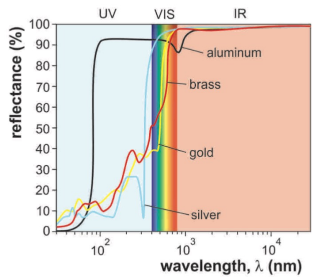
- wavelength

Reflection spectrum:

color 1 (reflected light)



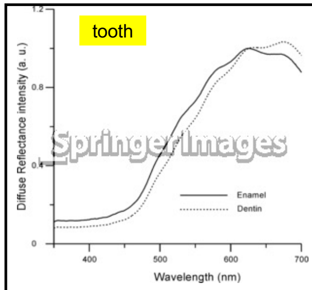




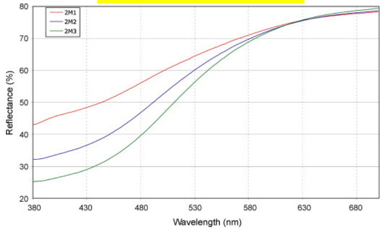
20

20

tooth

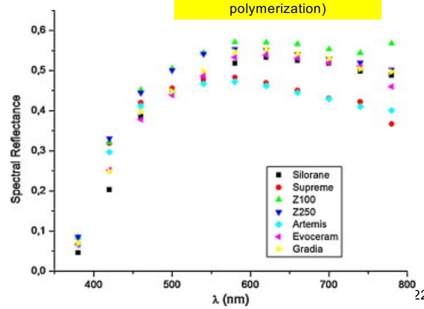


dental ceramics



Dental resin composite	Manufacturer	Organic matrix	Filler particle type	Filler particle size (μm)
Filtek Silorane		Silorane	Quartz filler, yttrium fluoride	0.1–2
Filtek Supreme XT		Bis-GMA, UDMA, TEGDMA and Bis-EMA	Zirconium-Silica agglomerate, highly dispersed silica	0.6–1.4
Filtek Z250		Bis-GMA, UDMA and Bis-EMA	Zirconium, Silica	0.01–3.5
Z100		Bis-GMA and TEGDMA	Zirconium, Silica	0.01–3.5
Gradia Direct		UDMA, dimethacrylate co-monomers	Silica and pre-polymerized fillers	0.007–1.7

dental composites (after polymerization)

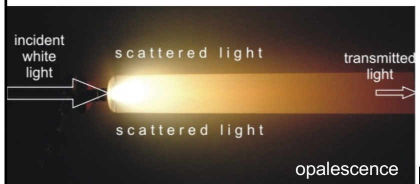


2. Scattering:

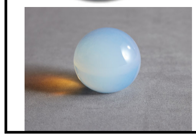
Spectral scattering $\sigma(\lambda)$: $\sigma_\lambda = \frac{J_{scattered}}{J_{incident}}$

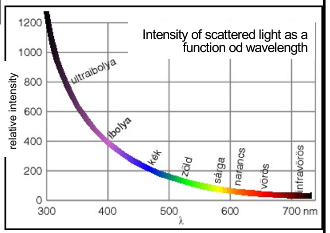
- **elastic scattering** (λ, f, ε do not change)

Rayleigh-scattering (particle size << λ)



spectrum of scattered portion: $\sigma \propto \frac{d^6}{\lambda^4}$

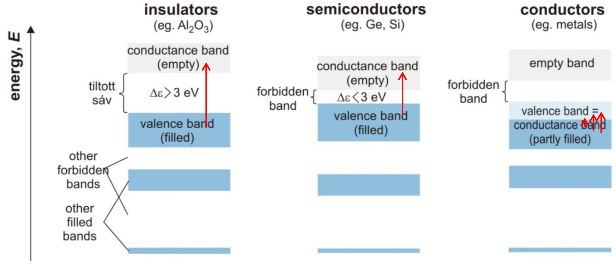


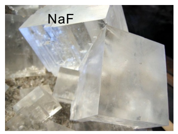


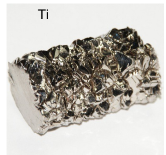
3. Absorption:

Spectral absorbance $\alpha(\lambda)$: $\alpha_\lambda = \frac{J_{absorbed}}{J_{incident}}$

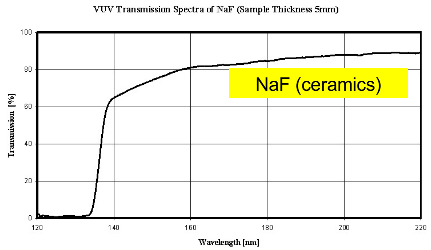
Absorption spectrum:





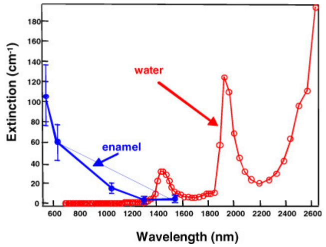


NaF



!

Extinction = scattering + absorption:



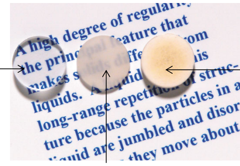
25

25

4. Transmission:

Spectral transmittance $\tau(\lambda)$: $\tau_\lambda = \frac{J_{transmitted}}{J_{incident}}$

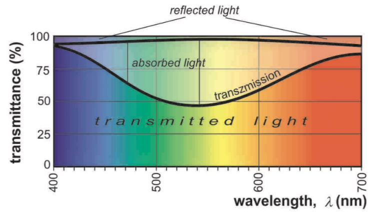
transparent $\tau = 1$

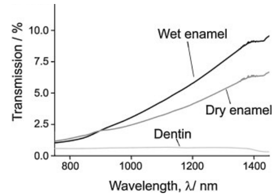


opaque $\tau = 0$

translucent $0 < \tau < 1$

$$\rho(\lambda)+\sigma(\lambda)+\alpha(\lambda)+\tau(\lambda)=1$$

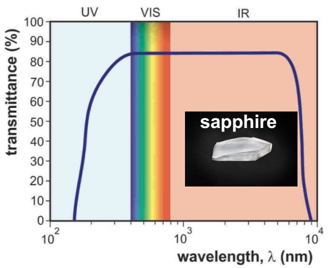


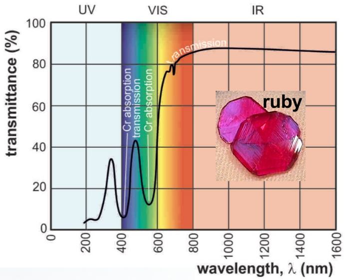


26

26

Transmission spectrum:



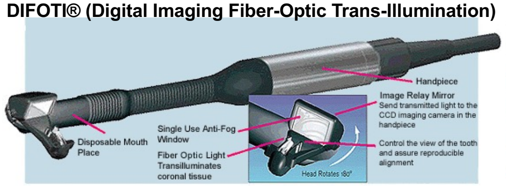


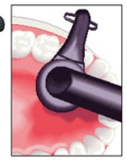
color 2
(transmitted light)

27

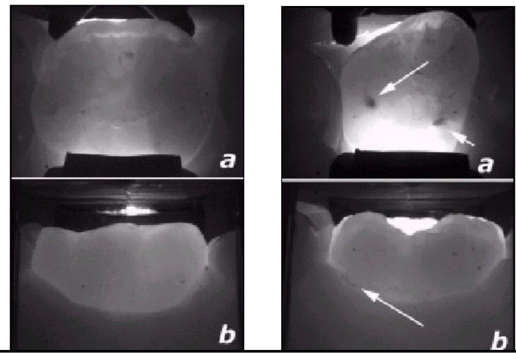
27

DIFOTI® (Digital Imaging Fiber-Optic Trans-Illumination)





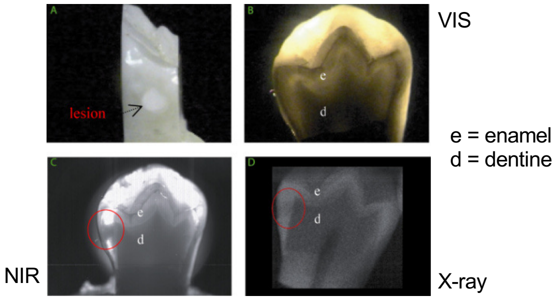
DIFOTI ® transilluminates #20 on the facial (labial) side of the pre-molar and images the lingual side.

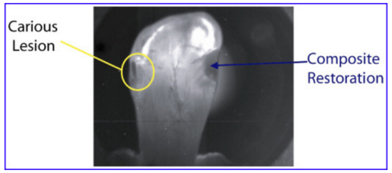


28

28

Trans-illumination in near infrared (NIR)



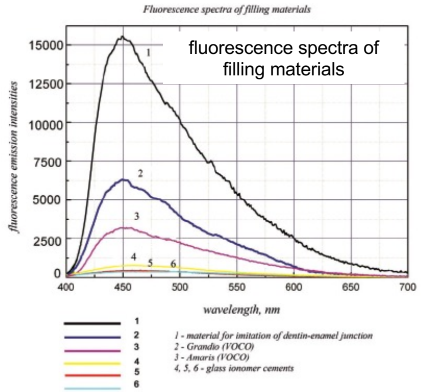


29

29

5. Fluorescence

fluorescence of enamel



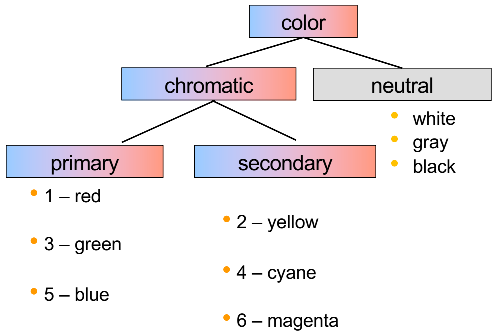
30

30

31

31

Color

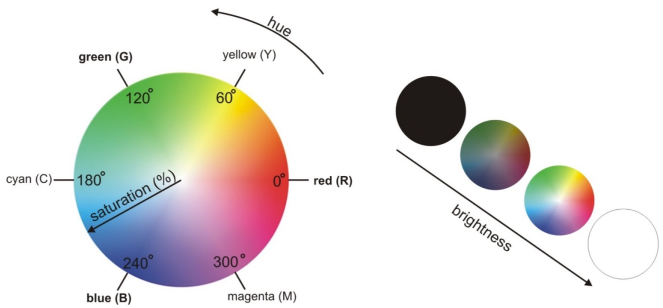


32

32

color coordinates

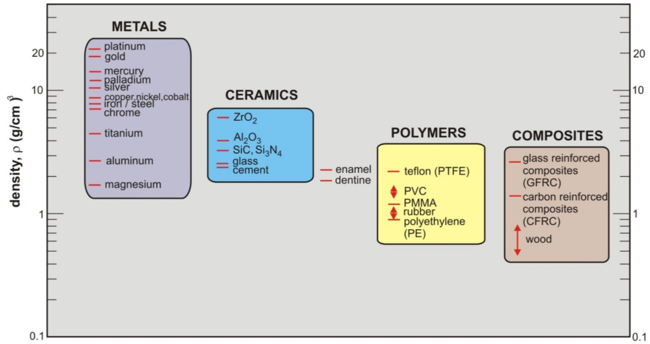
- hue
- saturation
- brightness



33

33

Comparison of dental materials

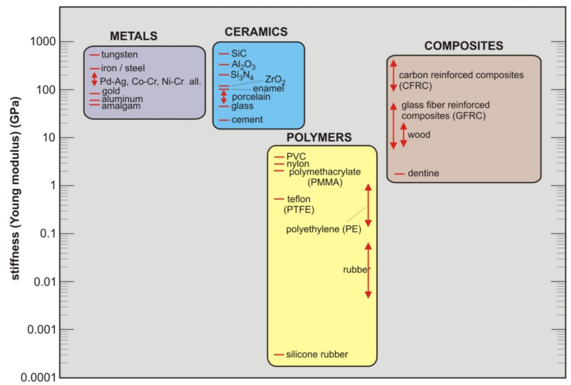


Density: polymers, composites < ceramics < metals

Depends on atomic mass, packing ratio

34

34



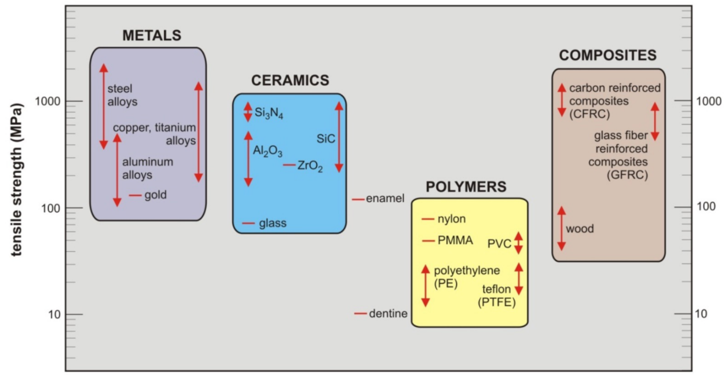
Stiffness: polymers < composites < metal, ceramics Depends on: bond energy

Resilience: ceramics < metals < composites < polymers

Ductility: ceramics < metals, composites, polymers

35

35

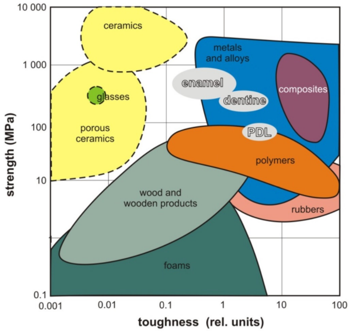


tensile strength: polymers < composites, ceramics < metals
Depends on: bond energy, crack resistance (ductility, brittleness)

compressive strength: Crack formation is less dominant, so ceramics have higher value

36

36



compressive strength:
polymers < composites, caremics, metals

Toughness:
ceramics < polymers, composites, metals
(strength, elastic strain recovery, plasticity)

Hardness:
polymers < composites < metals < ceramics
(stiffness and plasticity!)

37

37

Electric conductance: ceramics, composites, polymers < metals

Thermal conductance: ceramics, composites, polymers < metals
(correlates with electric conductance)

Melting point: polymers < composites < metals < ceramics
depends on bond energy

thermal expansion coefficient: ceramics < metals < composites < polymers
(inversely proportional to bond energy!)

Reflectance: ceramics, composites, polymers < metals
(in the VIS range, wavelength dependent!)

Transmittance: metals < composites < polymers, ceramics
(in the VIS range, wavelength dependent!)

38

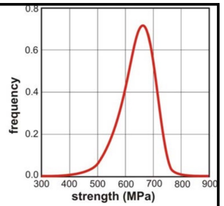
38

metals

In general:

- solid
- large density
- stiff
- strong
- ductile (malleable)
- tough (ductile fracture)
- hard
- low specific heat
- good heat conduction
- good heat shock resistance
- good electric conduction
- opaque, high reflectance
- poor corrosion resistance

ceramics



In general:

- solid
- medium density
- stiff
- strong (medium tensile strength)
- not ductile
- brittle (brittle fracture)
- „crack sensitive”
- very hard
- medium specific heat
- thermal insulator
- low heat shock resistance
- electric insulator
- diverse optical properties
- good corrosion resistance

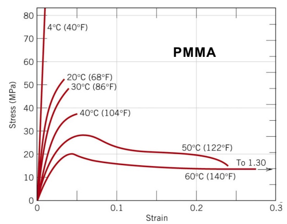
39

39

polymers

In general:

- liquid or solid
- low density
- low stiffness - elastic
- medium or weak strength
- ductile
- medium toughness
- medium hardness - soft
- viscoelastic
- medium specific heat
- thermal insulator
- medium heat shock resistance
- electric insulator
- diverse optical properties
- medium corrosion resistance



Important:

- temperature
- molecular mass
- degree of crystallinity

40

40

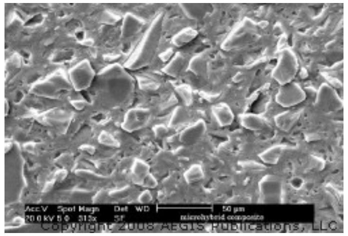
composites (dental)

In general:

- solid
- low – medium density
- medium stiffness - elastic
- strong
- ductile
- tough
- hard – medium hard
- viscoelastic
- medium specific heat
- thermal insulator
- medium heat shock resistance
- electric insulator
- diverse optical properties
- good corrosion resistance

Important:

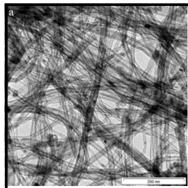
- composition
- particle size of dispersion phase



→ microhybrid → nanohybrid composites

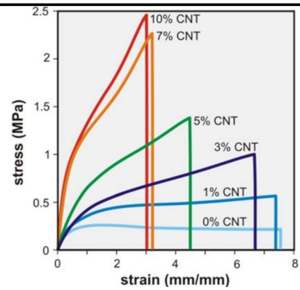
41

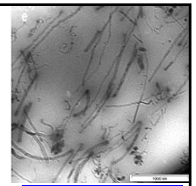
41



carbon nanotubes (CNT)

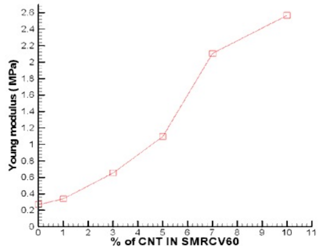
„combination of advantageous properties"

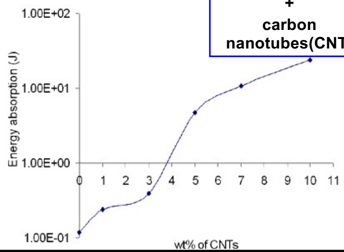




Composite:

standard malaysian rubber (SMR)
+
carbon nanotubes(CNT)





42

42