Intro to Biomaterials

- The success of any restoration is a combination of the patient, clinician and the material used. All need to work together to be successful

Classifications:

Preventative	Cement or coating to **seal pits and fissures** or **release therapeutic agent** (Fluoride) to **prevent/arrest demineralization** - ↓ Viscosity, ↑ wetting
Restorative	Metallic, ceramic, metal-ceramic or resin based material to **replace, repair, or rebuild** teeth/↑ esthetics - Metals, Ceramics, Polymers -> Composites
Intermediate	Cement or resin composite used for **few days-months** to temporarily replace/restore missing teeth.

Biological Properties of Dental Materials

Biocompatibility = Being harmonious with life and not having toxic effects on biologic function

Requirements:	Biocompatibility Depends on:
1. Not harmful to live tissues 2. Doesn't contain toxic substances with capacity to leach out causing local or systemic reactions 3. Not allergenic 4. Not carcinogenic	- Chemical and physical nature of its components - Types and locations of tissues it is exposed to - Duration of exposure - Surface characteristics of material - Amount and nature of substances leached from material

***** It is impossible to be completely free of all of these requirements. We must calculate risk and tolerance when choosing materials*****

Adverse Reactions

- Mutagenicity/Carcinogenicity/Teratogenicity
- Allergic Reactions (immediate or delayed)
  - Metal allergies (Nickel etc)
- Irritant (Non-allergic)
  - Gingival inflammation from surface roughness
- Intolerance

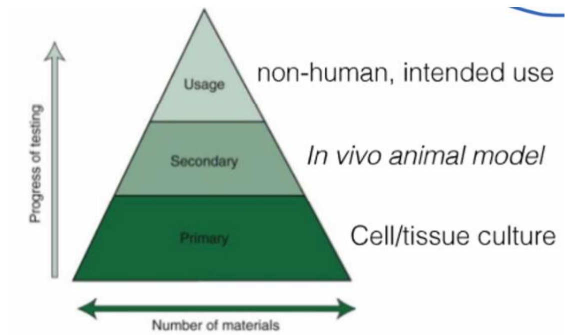
There is a hate on for amalgam everywhere today. However the alternative that everyone wants (resin composite) is actually way more harmful to tissues and the environment than amalgam is. Lack of knowledge in the general public

How Safe are Dental Materials?

Regulations held by:

- ISO 14385 (international)
- Health Canada
- ADA
- FDA
- FDI

1. Materials have to go through rigorous pre-market testing
2. Once approved they receive a Medical Device License (MDL)
   - Anything without an MDL is not approved and sketchy to use (can be found on ebay from overseas)
3. Materials are classified based on risk assessment, invasiveness, contact duration, nature of material etc:

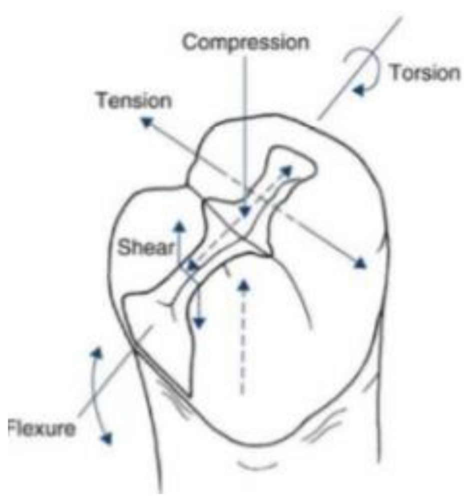


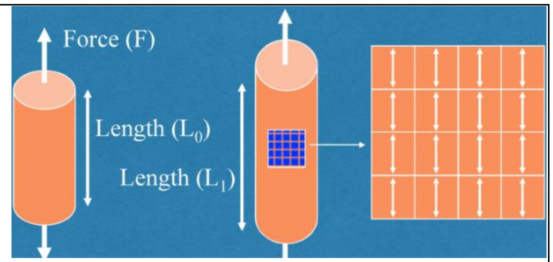
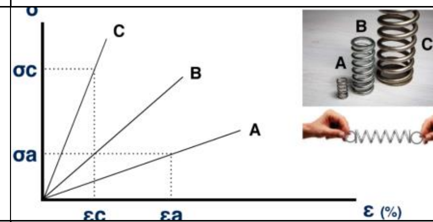
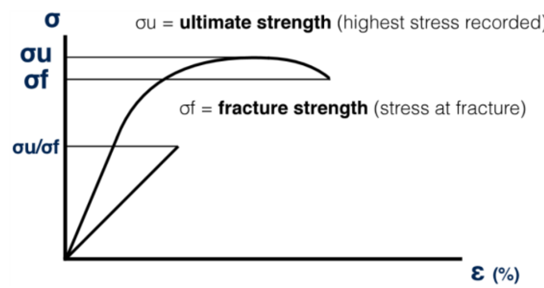
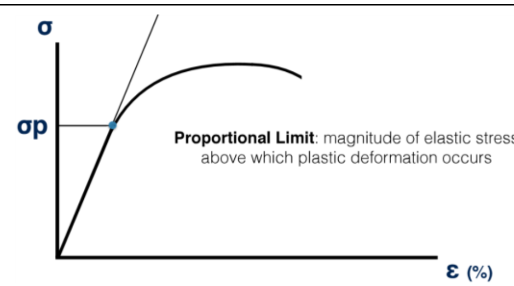
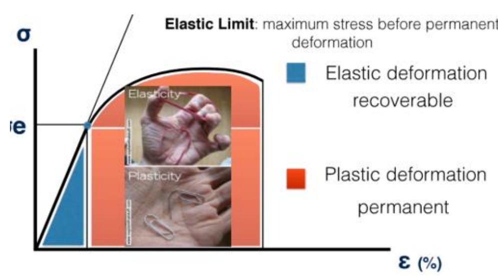
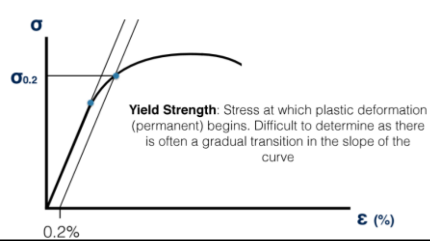
Class I	Not permanent in the mouth, often just instruments - Light curing unit
Class II	Restorative materials that are either temporary or permanent but don't resorb. - Resin Composite, Amalgam etc
Class III	Resorbable and absorbable materials that will be resorbed into the body - Resorbable sutures and hemostatic agents
Class IV	Drugs - Injectable or oral

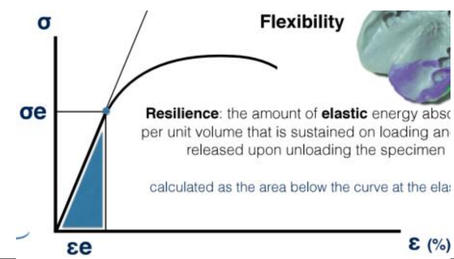
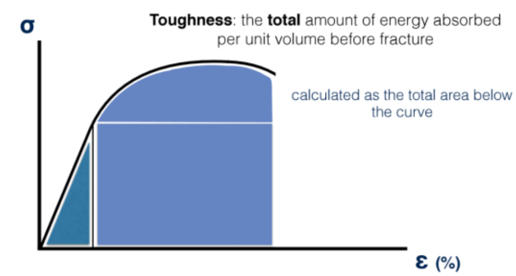
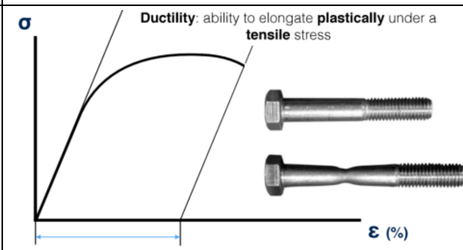
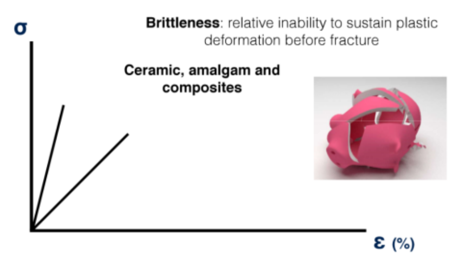
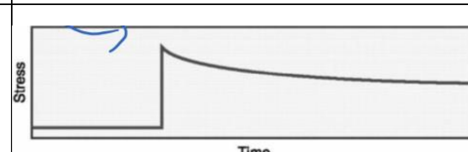
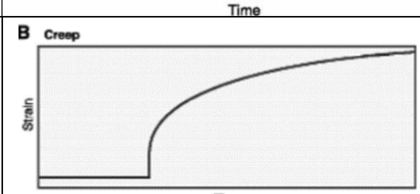
Mechanical Properties

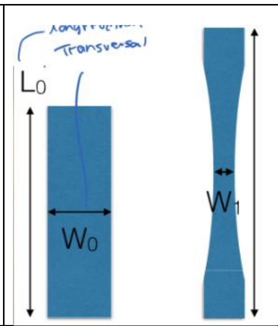
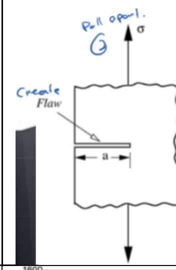
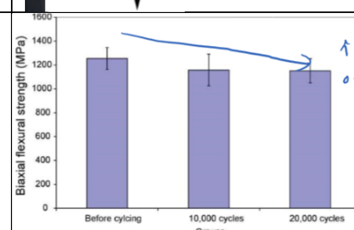
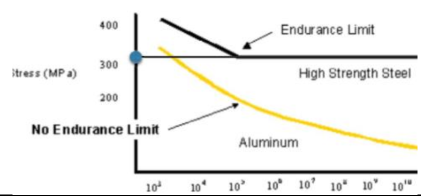
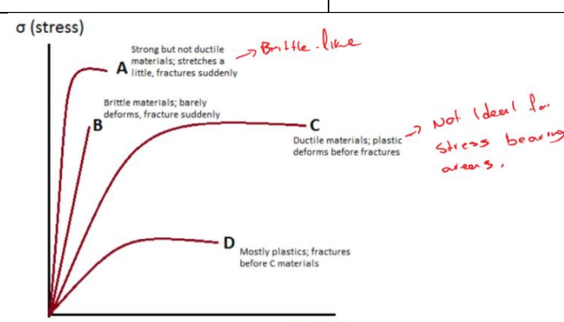
Intraorally, there are multiple stresses acting on materials -> Combinations of tests are executed to collect meaningful info about the material.

- Tests are used also to test interfacial bond strength between 2 bonded materials



Stress (σ)	Force per unit cross-sectional area acting on a material - Used to standardize the force on a material regardless of the geometry/thickness	
Strain (ε)	Fractional change in the dimension caused by the force - Expressed at a %	
Modulus of Elasticity (Young's Modulus)	Describes how soft/plastic or how hard/rigid a material is - Slope of the Stress/Strain Curve - Steeper curve, harder it is to deform	
Ultimate Strength (σu)	Highest Stress recorded - Maximum point of stress = can cause deformation - **Not necessarily the fracture strength**	
Fracture Strength (σf)	Stress at time of fracture	
Proportional Limit / AKA Elastic Limit / AKA Elastic Stress	Magnitude of elastic stress above which plastic deformation occurs: - Up to this point, stress can be removed, and the material will return to its previous shape. - After this point permanent deformation occurs Area Under Elastic limit = *Elastic Strain* Area under beyond elastic limit = *Plastic Strain*	
Yield Strength	Stress at which plastic deformation (permanent) begins. - Tough to measure because of the gradual transition in the slope - Arbitrarily measured at 0.2% Strain	

Flexibility / Resilience	Amount of elastic energy absorbed per unit volume that is sustained on loading and released upon unloading. - Area below curve at the elastic limit	
Toughness	Total amount of energy absorbed per unit volume before fracture - Total area below curve	
Ductility **Malleability**	Ability to elongate plastically under a tensile stress - The curve bends before fracture - Also typically tough due to ↑ area under curve Ability to sustain considerable permanent deformation without rupture under compression (hammering)	
Brittleness	Inability to sustain plastic deformation before fracture - No curve	
Stress Relaxation	Gradual ↓ in stress when strain is kept constant	
Creep	Gradual ↑ in strain when stress is kept constant	

Poisson's Ratio	Ratio between transversal strain and longitudinal strain within the elastic limit - Most materials are <0.5 and are constant for each material (non-changing value)	
Griffith Theory of Brittle Fracture	All materials contain imperfections (porosity etc) that act as stress raisers. - If force load reaches stress raisers = can have a fracture at stress below the theoretical limit	
Fracture Toughness	Measure of the ability of materials to resist propagation of a crack	
Fatigue	Gradual accumulation of minute amounts of plastic strain produced with cyclical fluctuating stress - ↑ imperfections = ↑ rate of fatigue - ↓ strength over time	
Endurance Limit	Level of stress below which the material can be subject to indefinite cycles of stress without fracture	
Hardness	Resistance of material to plastic deformation produced by indentation force - Want to aim for hardness equal to tooth. ↓ hardness will wear faster, and ↑ hardness will damage teeth in contact - Used to calculate level of curing in a material	
In Summary		

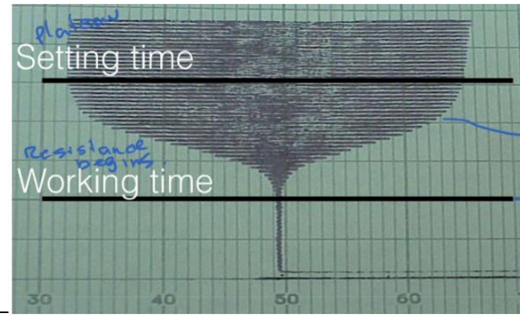
Chemical Properties

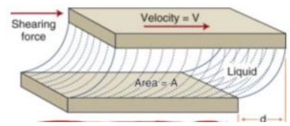
Rheology

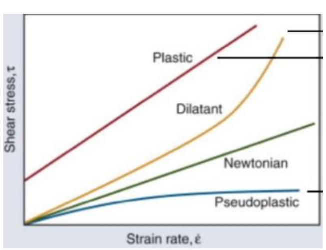
= study of flow and deformation (Viscosity)

Rheometer -> Used to measure viscosity

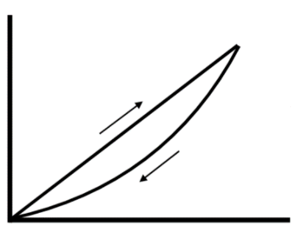
- Directly related to setting time with dental materials -> VERY important for us to be familiar with



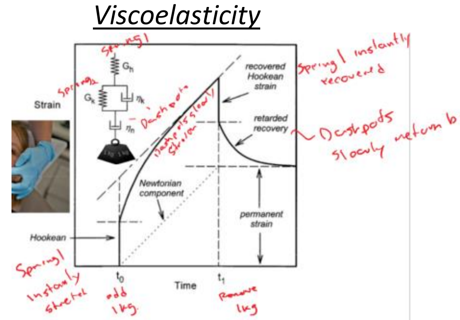
Viscosity	Resistance of a liquid to flow - Depends on ***intermolecular attraction and molecular weight*** When liquid is placed in motion -> Shear stress is generated - Viscosity = sheer stress/strain rate 
Plastic	Needs high stress to initiate movement (Ketchup in Heinz bottle)
Dialant	Material becomes more rigid with faster stirring (Gypsum)
Newtonian	Ideal, typical of most liquids
Pseudoplastic	Material becomes thinner with faster stirring, forced through a syringe or squeezed (Alginate)
Thixotropic Material	Fluid becomes less viscous and more flowable with repeated stress - Energy transferred throughout gel to make it a liquid *Clinical Correlate* *Fluoride Gel: Don't want it to flow everywhere when putting in in the tray, but when patient bites into it the energy transfer turns gel into liquid so it can flow into the cracks and fissures.*
Viscoelasticity	Viscoelastic when stress-strain relationship is *time dependant* - When stress is added, strain slowly increases over time. When stress is removed the strain rapidly drops until it begins to plateau at a place of permanent strain. *Clinical Correlate:* *Alginate setting: Teeth add stress. When removed a permanent strain is seen by the impressions being retained.* *Amalgam Creep: As time ↑ stress causes permanent deformation.*



__Thixotropic Material__



__Viscoelasticity__



Heat

Thermal Conductivity (k)	Quantity of heat transfer through a metal -> Ability of metal to transmit heat - Insulators vs Conductors - ↑ K and ↑h = Conductor (Pure Gold) - ↓ K and ↓ h = Insulator (Glass Ionomer) Polymers < Ceramics < Metals
Thermal Diffusivity (h)	The speed at which a temperature change spreads through the material
Specific Heat (C_p)	Quantity of heat needed to raise the temp of a unit mass by 1°C

Coefficient of Thermal Expansion (α)	Change in length per unit of original length when temperature ↑ by 1°C - ↑ value = easily changes shape when heated (Wax for example). - Contracts w/ cold; Expands w/ Heat ***Clinical Correlate:*** *Restorations in contact with cold temps (Ice cream etc) can contract if α is high = Pulls up on dentinal fluid out of the pulp = pain. With heat it adds pressure = pain.* *- We want a material with α similar to enamel and dentin, so the expansion and contraction occurs at the same rate*
h=k/C_p x Density	High density and high specific heat will have low thermal diffusivity

Tarnish and Corrosion

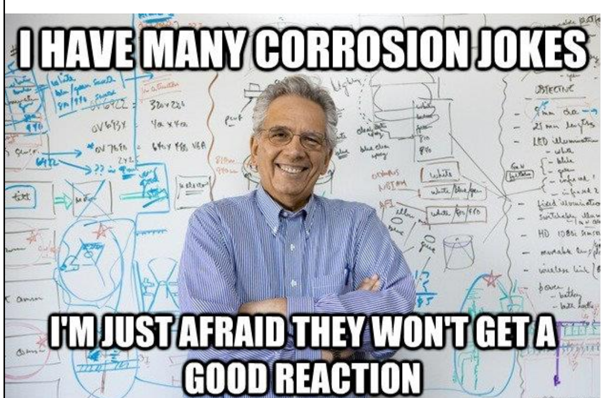
Tarnish = Discoloration of metal surface from oxide, sulphide, and/or chloride deposition on the surface.

- NOT a deterioration of the surface and is easily removed with polishing.
- Precursor to corrosion

Corrosion = Deterioration of a metal caused by a reaction with the environment.

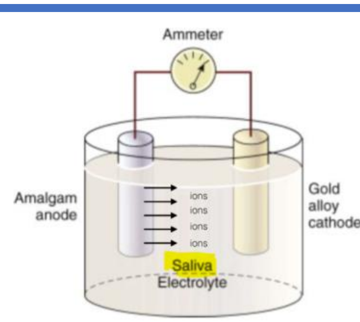
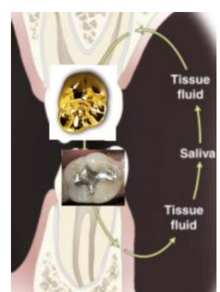
- Always involved loss of an electron during an oxidation reaction

<table>
<tr><th>Dry Corrosion</th><th>Wet Corrosion</th></tr>
<tr><td rowspan="5">- Occurs in absence of moisture (duh)
- Direct attack of chemicals on metal surface
- Slow process
- Corrosion products produced at corrosion site
- Uniform process



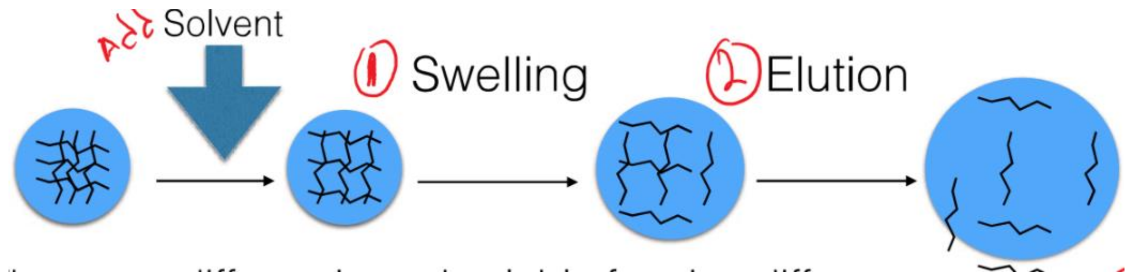
…Damn this joke is dry…dry corrosion get it?</td>
<td>- Occurs in presence of conducting medium
- Formation of electrochemical cells
- Rapid Process
- Corrosion occurs at anode, Rust deposited at cathode
- Process depends on size of anodic part of metal</td></tr>
<tr><td>Electrochemical Wet Corrosion (Galvanic)</td></tr>
<tr><td>More +'ve the Electrode Potential (V) the more resistant to corrosion the metal is.
- Gold is very much non-corrosive

Clinical Correlate:
Galvanic current can occur between 2 dissimilar metals causing sharp pain
- Biting on aluminum foil with amalgam restoration
-Apply a copal varnish on resto to prevent this

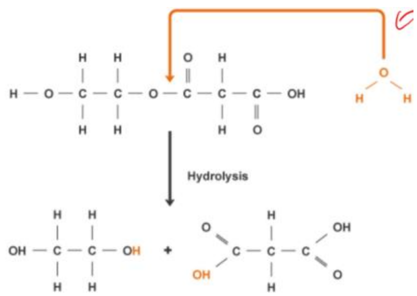


</td></tr>
<tr><td>Crevice Corrosion</td></tr>
<tr><td>Corrosion occurring in small crevices
- Typical with low copper amalgam alloys
- Deposition of corrosion products ↑ sealing of the margin.
- Totally a sweet feature of amalgam</td></tr>
</table>

Water-sorption and Solubility of Polymers

1. Solvent is added
2. Swelling of the polymer occurs
3. Soluble fraction loosens and is eluted out of the polymer into the environment (health risk)
4. Causes softening of the polymer, and scission (sick word, means cutting) of covalent bonds
5. Dissolution of the polymer by hydrolysis.

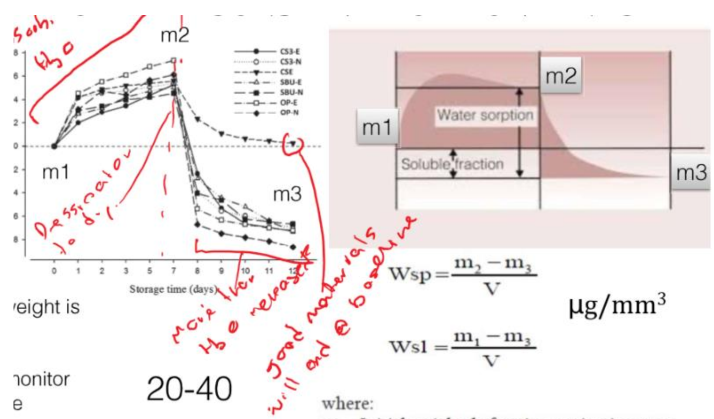


- Water always enters the polymer at the ester linkage to hydrolyze



Evaluate the water-sorption of materials to evaluate how long they will last in the mouth:

1. Between M1 and M2 water is absorbed and mass ↑
   a. Hydrophobic materials will ↑ less than hydrophilic
2. At M2, material is placed in a desiccator to remove the absorbed water
3. Mass measured at M3:
   a. An ideal material will end back at baseline. Indicating the polymers didn't solubilise and leach out during the absorption phase. If it drops below baseline, indicative that material was solubilized and leached out



****Water-sorption and solubility ↓ modulus of elasticity and ↓ ultimate tensile strength****

- Manufacturers will ↑ filler and ratio of hydrophobic monomer to ↓ Ws and Wsl
- Clinicians should ensure adequate polymerization and avoid internal porosity to ↓ Ws and Wsl

Structure of Matter, Principles of Adhesion

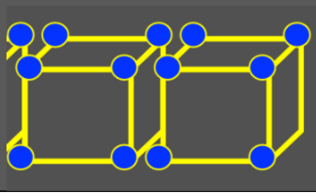
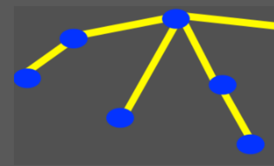
Interatomic Bonds

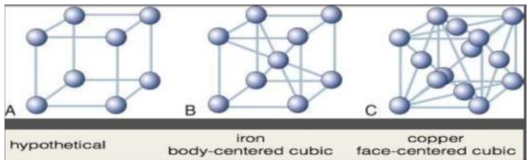
Primary Bonds	**Covalent**	Electron sharing - Makes molecules very stable - Strongest interatomic bond according to Dr. Carvhallo Ex: Denture materials
	Ionic	Electron Transfer - Stable Compound - Intermediate strength Ex: Brittle materials (Gypsum, Stone, Ceramics)
	Metallic	Electron Cloud - Weakest of primary bonds - Not strong - Excellent thermal and electric conductivity (from free movement of valence electrons)
Secondary Bonds	**van der Waals forces**	Charge variations among atomic groups inducing dipole forces that attract adjacent molecules or parts of large molecules - No electron Sharing - Weak force
	Hydrogen Bonding	***Most important bonding in dentistry*** - Form between -OH of a molecule with H atom of another molecule in the area - Early stages of water-sorption in composites and inter-peptide bonds of collagen fibrils

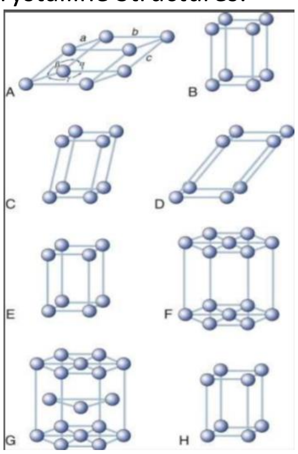
Energies

Bonding Energy	= Energy required to separate 2 atoms - Associated with distance between 2 neighbouring atoms (which is limited by diameter of atom and size of electrostatic field) ****Covalent > Ionic > Metallic**** *Attraction Forces:* - Keeps atoms bonded - As attraction ↑, interatomic distance ↓ *Repulsion Forces:* - Inactive until atoms approach each other - Active when proximity exceeds equilibrium
Thermal Energy	Determined by kinetic energy of atoms at a given temperature - ↑ Temp: ↑ amplitude of atomic vibration, ↑ internal energy, ↑ interatomic distance = Thermal Expansion! (When you heat something up it expands)

Crystalline and Non-Crystalline Structures

<table>
<tr><th>Crystalline</th><th>Non-Crystalline</th></tr>
<tr><td></td><td></td></tr>
<tr><td>Atoms spatially organized and ordered

3 Lattice Arrangements: 

Crystalline Structures:


A: Rhombohedral
B: Orthorhombic
C: Monoclinic
D: Triclinic
E: Tetragonal
F: Simple hexagonal
G: Close-package Hexagonal
H: Rhombic

<u>Clinical Correlate:</u>
Structures change based on stimuli you put on material
- Zirconia: Tetragonal when stable in mouth, when use burr on it becomes monoclinic -> unstable, lost most of its strength properties</td><td>Atoms and molecules spatially disordered

Internal energy of these structures is much higher than crystalline

No defined fusion temperature, and gradually melt as temp is ↑</td></tr>
</table>

Diffusion

- When internal energy becomes higher than bonding energy, atoms can move about within the lattice to other positions. Empty spaces (vacancies) act as pathways for atoms to move/diffuse.

Diffusion Coefficient: Amount of substance that diffuses across a unit area through a unit of thickness of substance in a unit of time (omg so many units)

Adhesion

<table>
<tr><td>Mechanical Adhesion</td><td>Penetration of adhesive into surface irregularities of the adhered

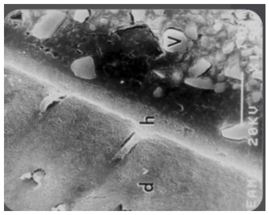
Micromechanical is a common bond formed in dentistry creating and using micro porosities (acid etching).

<u>Acid Etch:</u>
- Removes impurities
- ↑ Surface Energy
- Forms Micro-porosities for retention</td></tr>
<tr><td>Surface Energy</td><td>Atoms at the most outer layer of a solid have ↓ stability compared to inner atoms -> more prone to react
- ↑ surface energy by removing impurities on surface (its hard to bind to dirt)
- ↑ the surface energy = ↑ ability to bond</td></tr>
</table>

Wetting

Ability of a liquid to flow easily over the entire surface and adhere to the solid

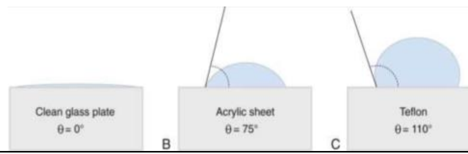
- Depends on the smoothness and cleanliness of surface (why its so important for everything to be clean!)
- ↑ wetting ↑ adhesive penetration into surface porosities = stronger bond



Hybrid layer = mixture of leftovers from acid etching (non-minerals) and resin monomers. The layer creating the micro-mechanical retention

Contact angle of wetting: Angle formed between liquid surface and solid surface

- Angle ↓ (liquid spreads) when attraction of adhesive to the surface is stronger than the cohesive force within the adhesive
- >90° = Hydrophobic
- <90° = Hydrophilic



Definitions

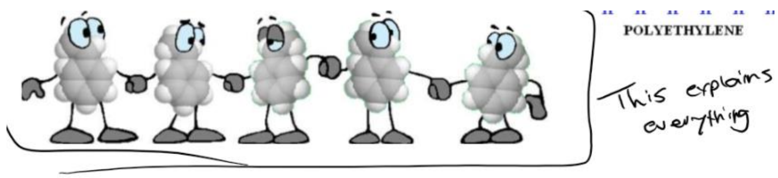
Adhesion = When unlike molecules adhere or are attracted

Cohesions = when alike molecules adhere or are attracted

Adhesive = The material used to produce a bond

Adhered = The material to which an adhesive is applied

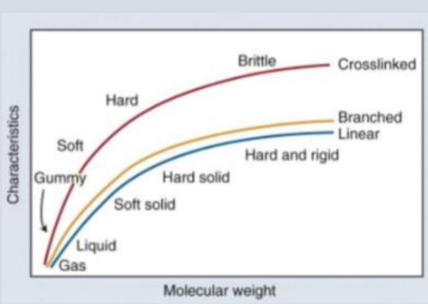
Polymers and Polymerization



This explains everything

Polymer = large organic molecule formed of many smaller repeating units (monomers)

- As chain length ↑, Branching ↑ or cross linking ↑
  = **↑ Rigidity, ↑ Strength, ↑ Melting Temp**



Monomer: Chemical compound capable of reacting with itself to form a polymer

Copolymer: Polymer with *2+ types of monomers* (slight variations of a basic monomer)

Monomer Clinical Correlates:

Methyl Methacrylate (MMA)

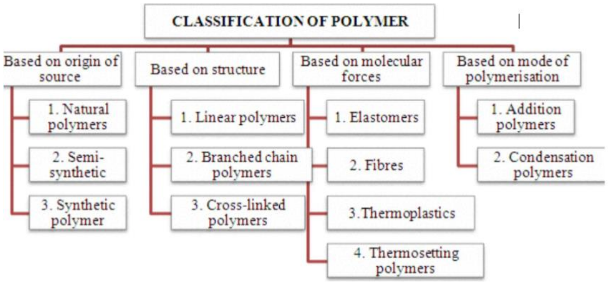
-> Polymethyl Methacrylate (PMMA) = acrylic material used for denture bases

Bis-GMA, TEGMA, EDMA

-> all di-methacrylate monomers = Co-polymers, found in RMGIC, Fissure Sealants etc

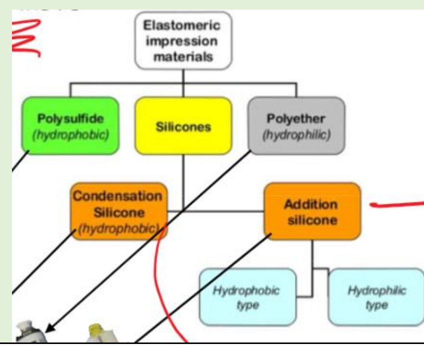
HEMA in nature is a liquid monomer

-> when polymerised into poly-HEMA polymer = Hard plastic

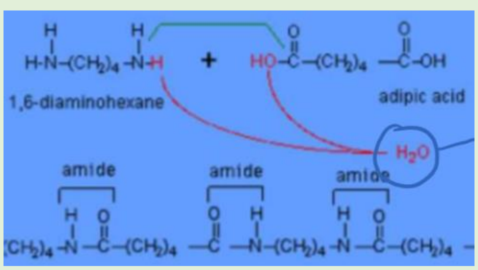
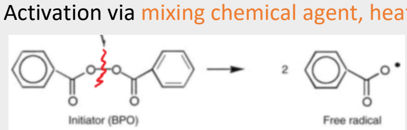
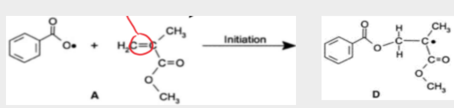


Fun Facts about polymers (seems like good Exam question fodder)
- Polymers usually absorb the solvent = swelling and softening -> Dissolution happens after its swole - Elastomers swell easier than polymers of plastics - Absorbed molecules (H_2O) spread apart the chains causing slippage = plasticization - Longer the chain (↑ Molecule Weight) = Slower dissolving - ↑ Crosslinks prevents chain separation = Cannot dissolve

Definitions

Term	Definition	Example
Thermoplastic	Softened by heating and solidified on cooling - Repeatable process	Gutta Percha Wax Some denture bases 
Thermoset	Solidifies during fabrication and CANNOT soften again on reheating	Composites Ceramics Acrylic bases Dentoforms?  
Elastomers	Polymers with elastic properties of a natural rubber - Resilient, Flexible *Condensation silicones* - lose molecules during condensation reaction = shrinkage *Addition Silicones* - don't lose anything = no shrinkage	Gloves Rubber Dam 

Polymerization

Condensation Reactions	Addition Reactions
= Results in the elimination of a smaller molecules (usually H_2O) - Causes polymerization shrinkage  	= No elimination of small molecules - Still get shrinkage though. As monomers come together the spatial distance between molecules ↓ = shrinkage (different from elastomers) **4 Stages:** **1. Induction (Activation + Initiation)** - Source of free radicals is needed for reaction to start -> Generated by ***activating*** **radical producing molecules -> BPO** - Activation via mixing chemical agent, heat, or Light exposure  - ***Initiation*** **= conversion of unstable C=C double bonds to stable C-C single bonds by free radical** -> Percentage of C=C to C-C conversion indicates the ***degree of conversion***  Typical reaction between BPO and MMA monomer - Free radical is propagated at the end of the molecule as polymerization carries on

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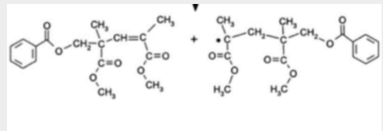
2. <u>Propagation</u>

The new free radical formed on the monomer reacts with neighboring monomer
= propagates the reaction forward

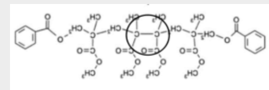
3. <u>Chain Growth and Transfer</u>

Multiple reactions occur at the same time with all the different monomers, as the chains grow they will eventually react with each other (instead of with more monomers)



4. <u>Termination</u>

- When 2 free radical chain ends interact



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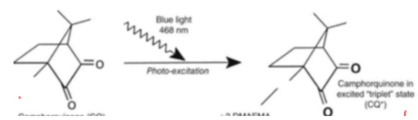
Light Activation of Polymerization

- No BPO molecule is needed or aromatic tertiary amines (Tertiary amines create a yellowing of material over time = bad)

<u>Step 1: Activation and Initiation</u>

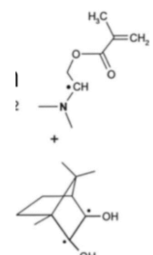
<u>Camphorquinone</u> (CQ) = **<u>activator</u>** molecule

- Blue light (468nm) causes photo excitation of CQ puts it in an excited "Triplet" state
    - No aromatic Tertiary amine formed = no color change over time!

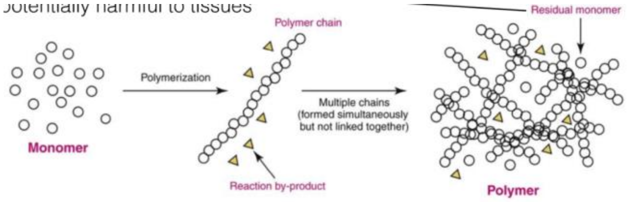


<u>Initiation</u>

- Activated CQ take a H atom away from the $-CH_2$ in the Monomer amine = Free radicals made of both the CQ and the initiating amine
- Free radical CQ deactivates immediately and free radical amines initiate the reaction

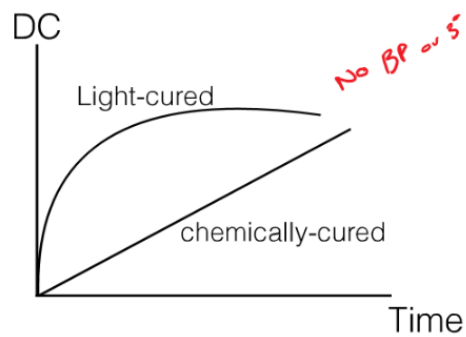


<u>Step 2-4: Occurs as a usual Addition reaction</u> (see above)



** No methacrylate polymerization reaches 100% Degree of Conversion.**

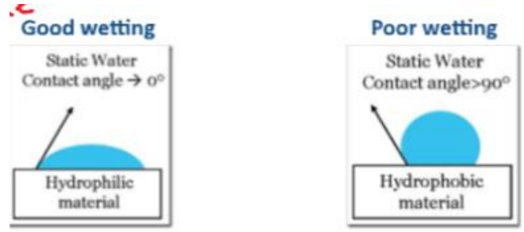
- As reaction progresses the molecular mobility ↓ so monomers will have a harder time making it through the matrix as the polymer stiffens
- Steric Hinderance between molecules ↑
- Residual monomer can leach out -> potentially harmful!



Dental Adhesives and Bonding

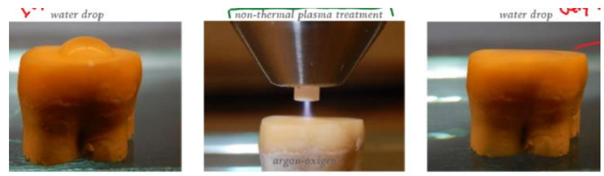
Adhesion Review

- No perceptible adhesion occurs between 2 solids…need a liquid to connect them by flowing into surface irregularities -> Wetting!



  - For good wetting we need a low contact angle
    - -> Surface energy of the solid is =/> surface energy of the liquid
  - Hydrophobic surfaces have ↓ surface energy and ↑ the contact angle

<u>*Can modify the surface energy for the application you are using:*</u>



- Smear layer = low surface energy -> Non-thermal plasma treatment to remove -> ↑ Surface energy

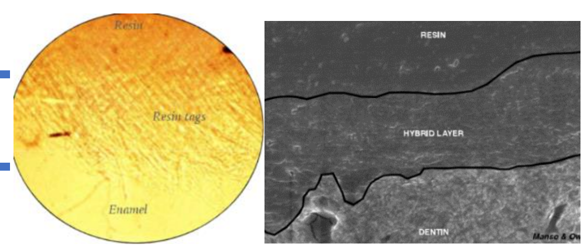
<u>*Or sometimes you want low surface energy to make a surface more hydrophobic (bonding to ceramics)*</u>

- Acid etching ↑ the surface energy -> Add silane to make it more hydrophobic -> ↓ surface energy so hydrophobic resin cement can bind!

<u>****Acid Etching is one of our main ways to ↑ the Surface energy of our bonding surfaces.****</u>

<u>**Acid Etching Dentin:**</u>	<u>**4 effects when we acid etch Enamel (demineralize surface):**</u>
Removing the smear layer and clearing the dentinal tubules = ↑ surface energy	1. ↑ the roughness 2. ↑ Surface area, 3. Create microporosities (micromechanical retention) 4. ↑ surface energy

Bonding Mechanisms



Micromechanical bonding is MOST important bonding in dentistry

2 Basic processes:

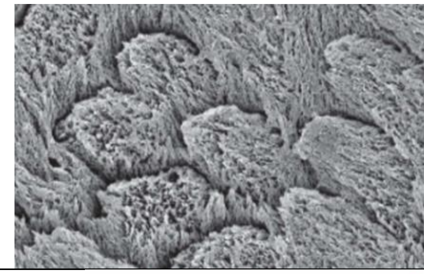
1. Removal hydroxyapatite to create microporosities (Acid Etch)
2. Microporosities infiltrated by resin monomers and polymerize

Acid Etching

Need to rinse for 10-15 sec. otherwise phosphate salts will remain on surface and interfere with bonding

Enamel

Etchant used: 32-37% Phosphoric Acid



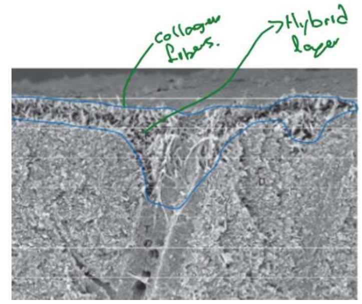
4 things happen:

1. Removal of mineral content
2. Cleans and roughens surface
3. ↑ Surface energy
4. ↑ Surface area

Imperative that enamel is clean (less important for dentin)

Dentin

Etchant: 32-37% Phosphoric Acid



What Happens:

1. Mineral content removed
2. ↑ Surface energy
3. Removes smear layer and plugs -> Leaves organic collagen exposed for binding

Acid activates Matrix Metalloproteases! -> Eat collagen

Etchant: 10-15% Polyacrylic Acid (**Conditioner**)

What Happens:

1. Removes superficial smear layer
2. DOESN'T remove smear plug within the tubules (This is fine, surface energy still ↑ for binding)
3. DOESN'T remove hydroxyapatite
4. ↑ Surface Energy
5. Enhances wetting for GIC's

Glass Ceramics

Etchant: 4-10% Hydrofluoric Acid

What Happens:

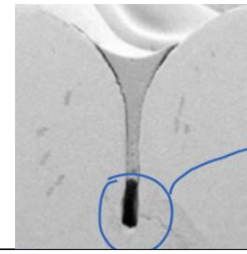
1. Selectively dissolves glass to create a porous surface (Silica only)
2. ↑ Surface bonding
3. ↑ Surface Energy
4. Create Hydroxyl groups (-OH) for chemical bonding with silane coupling agents

Natural DEJ Interface

	Enamel	Dentin	DEJ
Fracture Toughness	0.7-1.3 MPa $m^{1/2}$ (↓ than dentin)	1.0-2.0 MPa $m^{1/2}$ (↑ than enamel = ↑ stress to break)	Higher than enamel, lower than dentin
Hardness (Gpa)	3.5 (Harder than dentin)	1 (Softer than enamel)	↓ from enamel to dentin
Modulus of Elasticity	70 (Stiffer than dentin)	20 (more flexible than enamel)	↓ from enamel to dentin

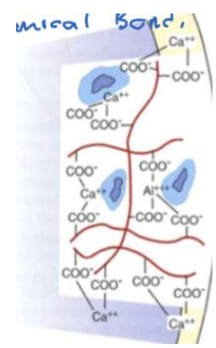
Pit and Fissure Sealants

****Low Viscosity is the most important feature. Allows penetration into tubules****

Components	1. ***Resin*** (BisGMA or UDMA) -> Monomers 2. ***Diluents*** (TEGDMA) -> ↓ viscosity 3. ***Fillers*** (Fumed Silica or inorganic glass) -> Not always present 4. **Activator-Initiator system**
Application	Important to use dental adhesive systems with sealants - Hard to keep bottom of deep tubules completely dry which can compromise seal of hydrophobic sealants - Adding primer and adhesive converts the "binding surface" to a hydrophobic one instead of hydrophilic H_2O = ↑ retention of sealant 
Essentials for sealant success	Good Cleaning Good Etching Good Rinsing Good Drying
GIC Sealants	Awful retention rate (<19%) HOWEVER: - After appearing lost clinically, it can still be found microscopically sealing the porosity and pits/fissures - Has shown that even if they look like they have fallen out they still sufficiently prevent caries.

Glass Ionomer Cements

Based on Indication			
Type I		**Luting Cement**	Luting crowns, Bridges and Ortho Brackets
Type II	**A**	**Esthetic Restorative Cement**	Restoratives
	B	**Reinforced Restorative Cement**	Core Build-up and ART
Type III		**Lining Cement or Sealant**	Liner and Sealant

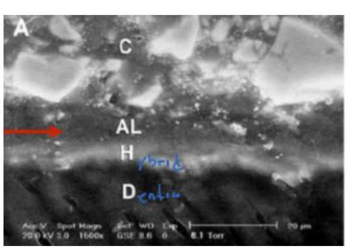


Chemical bond to tooth structure

- Carboxyl groups of the polyacrylic acids chelated with Ca^{++} in apatite of enamel and dentin

- DON'T etch Dentin (removes the essential Ca^{++}) but we DO etch Enamel (creates micromechanical retention, while still having sufficient Ca^{++})

- GIC cements are used to bond ortho brackets to teeth. The Fluoride release helps to prevent white spot lesions around the bracket -> Neat!



AL: Adsorption Layer (only found in RMGIC)

- Resin Rich, amorphous layer in between dentin bonded with RMGIC
- Involves water from hydrated dentin causing HEMA monomers of RMGIC's to swell
- Acts a stress relieving cushion to ↓ shrinkage stresses on bond interface. ↑ longevity of RMGIC's over GIC's

3 Bonding Strategies:

Cement Type	Requirements	Industry Examples
Non-Adhesive Cements	Requires an adhesive	Duolink, (Bisco) Choice 2 (Bisco) RelyX ARC (3M/ESPE)
Self-Etching Cements - Primer etches the surface and you add adhesive after	Requires a self-etch primer	Multilink (Ivoclar) GCem (GC) Smartcem2 (Dentsply)
Self-Adhesive Cements - 2-part materials -> Require hand mixing, capsule trituration or auto-mixing dispense - Contain Acid-Functionalised Monomers (4-META, MDP, Phenyl-P etc) o Achieves demineralization and bonding	No adhesive required	BisCem (Bisco) RelyX Unicem (3M/ESPE) SpeedCem (Ivoclar) MaxCem (Kerr)

Dental Adhesives

Components		Notes
Primers + Solvents	*Primer*: Hydrophilic monomers with one terminus being hydrophobic (HEMA) + Solvents (Ethanol, acetone, H_2O)	Monomers must have hydrophilic characteristics to allow adhesion to Dentin Solvents have higher ability to H-bond with collagen than collagen has with itself = opens interfibrillar space to ↑ resin penetration
Adhesives	High molecular weight dimethacrylates (bisGMA, UDMA) Low Molecular weight monomers (TEGMA)	Monomers with crosslink and copolymerization functions
Self Etch Adhesives	Acidic Monomers: Carboxylates - 4-META - MAC-10 - 4-MET Phosphates - 10-MDP (remember this for Zirconia) - P-Phenyl	The monomers etch the surface themselves, so no etching step will be needed

Goals of Adhesive Dentistry:

Adhesive

1. Improve bioactive characteristics
2. Enhance degree of conversion
3. ↓ hydrolytic degradation over time

Dentin

1. Inhibit host-derived enzyme activity (MMP's)
2. Improve collagen fibril coverage

Etch and Rinse Adhesives	
3 Step	Etch Primer (Hydrophilic monomer - HEMA; Solvents - Ethanol, Acetone, H_2O) Adhesive (Dimethacrylates-bisGMA, UDMA; Low MW Monomers – TEGDMA)
2 Step	Etch + Primer/Adhesive - Adhesive will not have an acidic monomer; primer and adhesive pre-mixed
Self- Etch Adhesives	
2 Step	Etch/Primer (4-META/10MDP/Phenyl-P + HEMA + H_2O) -> Acidic primer monomer Adhesive (Dimethacrylates-bisGMA, UDMA; Low MW Monomers – TEGDMA)
1 Step	Etch/Primer/Adhesive (sometimes in 2 bottles, mix, and apply only once in mouth)
Universal Adhesives - Only 1 Bottle	
2 Step	Etch (Optional) + Etching Primer/Adhesive - Can choose if you want to etch or not - Adhesive has acidic monomer, but if using it with enamel can use an additional (↑%) etch
1 Step	Etch/Primer/Adhesive - 10-MDP - Bis-GMA-UDMA-TEGDMA - HEMA - H_2O - Ethanol/Acetone

Water: GIC vs Adhesives

Waters Effect on:	
GIC	**Adhesives**
- Intrinsic component of GIC (a part of the ingredients) - Required by GIC for chemical reaction - Participates in GIC maturation - Helps form Adsorption Layer for shock absorption	- Deleterious to adhesive procedure - Compromises adhesive curing - Leads to adhesive deterioration

Enamel Bonding

Etch and Rinse Adhesives are the Gold Standard

- Good retention and sealing
- Good therapeutic Flexibility

….Not really much more to add here I guess?…

Dentin Bonding

Considerations of Dentin	Naturally wet substrate 30-50% collagen (↓ inorganic substrate vs enamel) **Requires hydrophilic monomers for primer** Contains MMP's (Matrix metalloproteases) -> Activated by highly acidic etching Morphology changes with depth Changes occur with aging and caries **VERY technique sensitive bonding**
Moisture	**Collagen is very sensitive to moisture** - *Too Wet*: Adhesive separation and poor infiltration - *Too dry*: Collagen collapses = Monomer diffusion restricted and poor infiltration Blot dry with micro-brushes or tissue pieces -> NO air drying, doesn't get the corners dry. **Solvents:** Ethanol Based – able to produce the ***strongest bond***, but is fairly ***sensitive to moisture*** Acetone Based – Able to produce sufficiently strong bonds over a wider range of moistures (***less sensitive to moisture***) -> best middle ground maybe? Water Based – Produces the weakest bonds of the 3 and is sensitive to moisture. (generally quite shitty)
Hybrid Layer	Resin impregnated dentin layer. The junction where both dentin and resin are present - The goal is to completely infiltrate resin monomers into demineralized collagen however its impossible to COMPLETELY displace all the H_2O from the collagen - ***Primer w/solvents helps chase out H_2O and expand the fibrils*** for easier infiltration - Hybrid layer susceptible to degradation
Collagen Degradation	If unprotected, collagen fibrils can degrade even in absence of bacteria - Host derived Matrix Metalloproteases (MMPs) will break down exposed collagen = compromising bond with infiltrated resin Chlorhexidine (CHX) digluconate (0.2%) and benzalkonium chloride (BAC) for 60 sec. - Inhibits MMPs and ↑ longevity of bond.
Issues with Simplified Adhesives	1. Presence of hydrophilic monomers -> ↑ susceptibility to hydrolytic degradation 2. High Solvent and H_2O content -> Solvent and H_2O not completely removed in clinic 3. Variable degrees of conversion -> Depends on residual Solvent and H_2O (↓ conversion with ↑ residual solvents) **Lightly Air dry and use rubbing action when applying primer to evaporate solvent and penetrate sufficiently, use micro-brush to remove excess** *Rubbing primer in:* - ↑ resin infiltration - ↓ effects of surface moisture - Improves solvent evaporation - ↓ phase separation in simplified systems
Clinical Procedure	1. Etch with Phosphoric Acid 2. Rinse 15 sec with water and airdry 3. Re-wet with CHX (2%) -> refluffs collagen, blot dry (DON'T RINSE) 4. Apply Primer/Adhesive -> Rubbing 5. Evaporate solvent (30sec) and cure
Which System do we use?	**Self Etch Adhesives (2 Step):** - Demineralize and infiltrate surface simultaneously (as infiltrate deeper, acidic monomers are buffered by mineral content of substrate). Adhesive is added in 2nd step - 1 Steps are prone to degradation. Too hydrophilic, behaves as a permeable membrane *In Dentin:* - ↓ risk of incomplete adhesive penetration - ↓ subjectivity when evaluating amount of moisture on surface - Less sensitive to structural alterations of dentin - Mostly micromechanical retention (but also some monomers binding to HA) - Don't use strong self-adhesives: $Ca(PO)_4$ wont wash away and weakens interfacial integrity *In Enamel:* - Poor micromechanical Retention (not enough etching) - Must selectively etch enamel with phosphoric acid 37% 10sec before self etch adhesive application
Dentin Bonding Challenges	Radicular Dentin (cementing posts): - NaOCl used to cleanse the root canals compromises bond (DON'T USE) - Use Chlorhexidine to cleanse canal -> Better bonding - ↑ C-factor because cannot apply in layers - Use Conditioner and a dual cure self adhesive resin cement to ↑ bonding - Can be luted with GIC luting cements also

Universal Adhesives

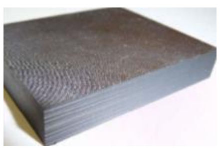
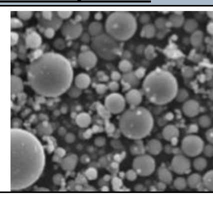
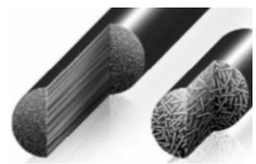
- Can have Etch and Rinse technique or Self-Etch (Multimode)
- Still allows chemical bond between carboxylic or phosphate groups from the monomers and residual HA crystals

Enamel Bonding	Selective enamel etch and rinse recommended - achieve sufficient ↑ in surface area, surface energy, and micromechanical retention.
Dentin	Self-Etching Recommended - Found ↓ bond strength, ↑ leakage when Etch and Rinse used

---

Resin Composite

= material system comprised of 2 phases (Matrix and Dispersed) -> must be chemically dissimilar and separated by distinct interfaces.

Laminar Composite	**Particulate Composite**	**Fiber-Reinforced Composite**
2+ layers of different materials bonded together 	Composite with embedded particles 	Composite of chopped or continuous fibers 

Dental Resin Composite

= Composed of organic resinous matrix, inorganic fillers, coupling agents, chemicals for curing

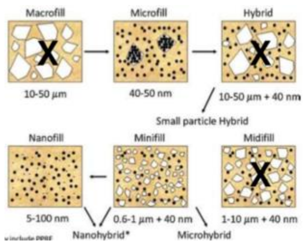
Trends in Composite development

Low Shrinkage	Composites with ↓ shrinkage or lower shrinkage stress - Used as bases or resto's
Bulk Fill	Enhanced depth of curing (4mm increments) - Used for bulk fill liners and resto's - Similar polymerization stress to conventional composites (not a stiffer material = more stress) - Lower filler content, improves light transmission = ↑ shrinkage - Has lower elastic modulus to ↓ stress/flex more = requires a cap with a highly filled material
Self-Adhesive	Flowable cements with self-adhesive properties
Bioactive	Composites and antimicrobials and mineralizing agents

Components

Main Constituents	**Side Constituents**
Polymeric Matrix Reinforcing fillers Silane coupling agent Chemicals for polymerization reaction	Pigments Antioxidants Inhibitors

Properties Influenced by	- Monomers (influence the amount of shrinkage). ↑ monomer = ↑ shrinkage - Filler size and content (Influences wear resistance and shrinkage) -> ↑ filler = ↓ monomer = ↓ shrinkage - Quality of bond between fillers and resin - Quality of polymerization

Component	Description	Example
Polymeric Matrix	One of main components by volume Changes in matrix aim to ↓ shrinkage upon polymerization - (although composites will ALWAYS shrink) Main changes = development of monomers with bulky/rigid central section and flexible ending groups	**Large Molecular Weight – Low Shrinkage** - Bis-GMA - UDMA **Low Molecular Weight – Higher shrinkage** - TEGMA - Bis-EMA - Used to ↓ viscosity of high MW monomers (allows the addition of filler while not being too thick) **Self Adhesive Acidic Monomers** - Phosphates (Phenyl-P, 10-MDP) - Carboxylates (MAC-10, 4-MET, 4-META) - Flowable (GPDM/Vertise Flow) -> Only one in the market
Reinforcing Fillers	Major portion by volume or weight: 1. **Reinforces matrix** 2. **Provides adequate translucency** 3. **Controls shrinkage** **Types:**  µm sizes are too large to resist wear and polish (why they are gone now) Microfill particles cluster together, makes it too viscous Microhybrid, nanohybrid, nanofill used mostly now Nanofills – All particles are <100nm (below visible light) makes them highly translucent. High surface area to volume ratio Most important properties of composites are **improved with ↑ Fillers** (Mechanical properties, wear resistance, strength, modulus of elasticity mainly), - <60% filler = Flowable -> ↓ fillers = ↑ shrinkage, not great for gingival margin - >60% Conventional - Limited to about 80% by volume due to the packing of the particles (best packing is done with hybrid types where smaller particles can fill in space between larger ones)	Quartz, Silica Glasses Ceramics Zirconia

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<tr><th><u>Type of composite</u></th><th><u>Size of fillers (µm)</u></th><th><u>Volume of filler</u></th><th><u>Advantages</u></th><th><u>Disadvantages</u></th></tr>
<tr><td>Multipurpose</td><td>0.04, 0.2-3.0</td><td>60-70</td><td>High Strength, High modulus</td><td></td></tr>
<tr><td>Nanofilled</td><td>0.002 – 0.075
(2-75nm)</td><td>78.5</td><td>High Polish, High strength, High modulus</td><td></td></tr>
<tr><td>Microfilled</td><td>0.04
(40nm)</td><td>32-50</td><td>Best polish, Best esthetics</td><td>Higher shrinkage
↓ Fracture toughness
↓ modulus
↓ flexural strength

- Good if only used for esthetics</td></tr>
<tr><td>Packable</td><td>0.04, 0.2-20.0</td><td>59-80</td><td>Packable, Less shrinkage, Less wear</td><td></td></tr>
<tr><td>Flowable</td><td>0.04, 0.2-3.0</td><td>42-62</td><td>Syringe-able, Lower Modulus, Lower viscosity</td><td>High Wear</td></tr>
<tr><td>Laboratory</td><td>0.04, 0.2-3.0</td><td>60-70</td><td>Best anatomy at contacts, low wear</td><td>Special equipment, requires resin cement</td></tr>
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<tr>
<td>Silane Coupling Agent</td>
<td><u>4 main functions of Silane</u>
1. Bridges/bonds filler to resin matrix (one side binds Monomer, the other side binds filler)
2. ↑ mechanical properties
3. Interfacial phase provides medium for stress relief
4. Creates hydrophobic environment to ↓ H_2O absorption

Comes from the factory bound to the filler already, when polymerization occurs will bond to matrix also</td>
<td>MPTS (3-methacryloxypropyltrimethoxysilane)</td>
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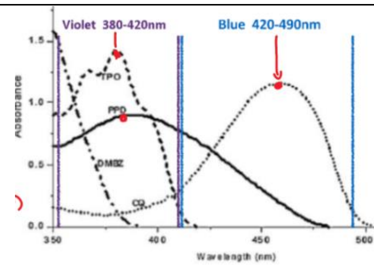
<tr>
<td>Photoinitiators</td>
<td><u>Camphorquinone (CQ)</u>
- Photosensitized by blue light (465nm) and accelerated by aromatic tertiary amines
- Bright yellow colour -> gives resto's a slight yellow colour

Traditional light curing units only emitted blue light, but with the new photoinitiators we need to have different options
- <u>Polywave LED</u> -> emission peak around 460nm for CQ, and additional peaks around 400nm for the alternative co-initiators
- Need to be aware of which composites have which initiators


</td>
<td>Camphoquinone

<u>Alternatives:</u> -> Synergistic if added with CQ, ↓ amount of CQ = ↓ yellowing

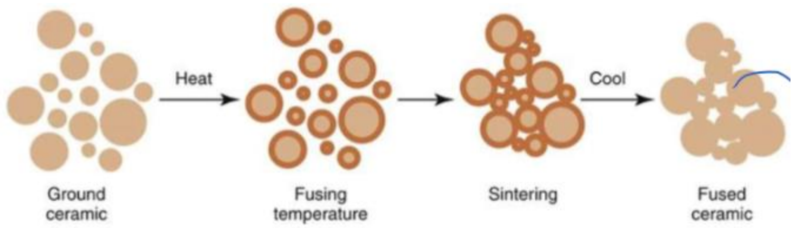
PPD shorter wavelength, needs violet to cure not blue
Lucirin TPO -> shorter wavelength, needs violet to cure not blue
Ivocerin
Irgacure</td>
</tr>
</table>

Dental Ceramics

If clay is heated to <900° C it is considered ***Earthenwear***. >900°C = ***Stonewear*** -> this was the original strong ceramic

-> The key is in the Sintering process. Loosely bound clay particles are heated to a fusion temperature and fuse into a coherent solid.

Porosity will always be found in the end product, the degree of porosity will depend on how you prepare the ceramic



Ingredients	Function
Feldspar	Fuses every component into 1 mass - Lowest fusion temps = melts 1st and flows during firing process
Silica (Quartz)	Contributes strength and stability during heating process by providing framework for other ingredients - Very high melting temp -> Remains unchanged during firing process
Kaolin (hydrated aluminosilicates)	Used as a binder - ↑ mold-ability of unfired porcelain - Gives opacity to finished product (this is how the Chinese made amazing porcelains back in the day)
Glass Modifiers (K, Na, Ca Oxides)	Interrupt integrity of silica network and act as flux - (↓'s the melting temperature on the components)
Color Pigments (Fe/Ni oxide, Cu Oxide, MgO, TiO_2, Co Oxide)	Give restoration different shades
Zx, Ce, Sn Oxides and Uranium Oxide	Develops opacity

Processing steps for dental porcelain

1. ***Compaction*** -> Paste of porcelain powder + H_2O compacted into a die
2. ***Firing*** -> ↑ temps sinter the elements together -> Results in significant shrinkage
3. ***Glazing*** -> Porous surface covered with glasses that will fuse at low temp.

Classification of Dental Ceramics

By Application	
w/ Metal	Metal-ceramic crowns Fixed partial Prosthesis
w/o Metal	All Ceramic Crowns Inlays Onlays Veneers Fixed Partial Prosthesis
By Fabrication Method	
Sintering	Firing compacted ceramic powder at high temps
Slip-Casting	"Slip" = aqueous slurry of ceramic particles
Heat-Pressed	External pressure at high temps to sinter and shape ceramic at same time
CAD/CAM	Milled from ceramic blocks
Combination techniques	Self-Explanatory duh
By Crystalline Phase	
↑/↓ Crystalline Phase	↑ phase = ↑ resistance to crack propagation (↑ Strength), but ↓ translucency (↓ Esthetics)

Feldspathic Ceramics	Reinforced Ceramics	Polycrystalline Ceramic
↑ Translucency ↑ Esthetics ↓ Strength	→	↓ Translucency ↓ Esthetics ↑ Strength
Very hard and Brittle		Mostly used as reinforcement substructure (like metal) that is veneered on top Ex: Zirconia

Metal Ceramics

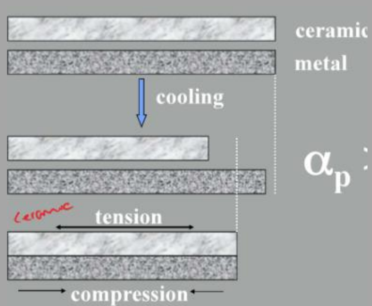
Requirements for Metal Ceramic Crowns:

1. Alloy must have **higher melting temp** (>100°) than firing temp of the veneer
   - Don't want the metal to melt when firing the porcelain
2. Veneering porcelain must have relatively **low fusion temp** (during sintering)
   - Don't want metal to distort under high temps during sintering
3. Porcelain must **wet** the alloy (Contact angle <60 degrees)
4. Good **bonding** occurs with 2 mechanisms:
   a. *Chemical Reaction:* Porcelain + Metal Oxides of the metal surface
   b. *Mechanical*: Micromechanical interlocking by ↑ metal surface roughness
5. **Coefficients of thermal expansion** must be compatible btwn porcelain and metal
   a. Porcelain slightly lower than alloy

If $\alpha_p > \alpha_m$:

= More expansion and contraction of porcelain vs. metal

- Causes ceramic to expand after cooling (back to normal), but metal to compress to meet the porcelain in the middle



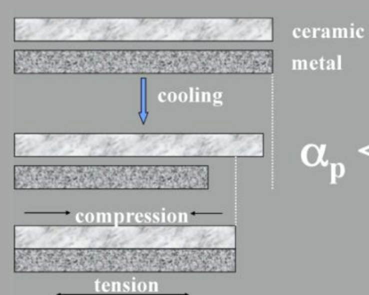
Results in a +'ve Stress

-> Closer to Fracture Stress

If $\alpha_p < \alpha_m$:

= More expansion and contraction of metal vs. porcelain

- Causes metal to expand after cooling (back to normal), but ceramic to compress to meet the porcelain in the middle



Results in a –'ve Stress

–> This is best. Farther from Fracture stress

6. Adequate **stiffness** and strength of metal
7. High **resistance to deformation** at high temps
8. Adequate **design** of restoration

Feldspathic Dental Porcelains

1. Glassy phase (80-90%). = Gives translucency similar to enamel (esthetics)
2. Leucite (10-20%) = Controls thermal expansion coefficient to match closely to that of the dental alloys

Characteristics:

- Fuse at ↓ temps than many other ceramics
- Very hard -> abrasive to opposing teeth
- Glassy phase is a lot like glass (↓ toughness and strength, but ↑ translucency)
- Glassy phase can be etched

All-Ceramic Restorations

Sintered All-Ceramics	
Alumina-Based Ceramic (~40-50% alumina)	1st aluminous core - ↑ Modulus of elasticity, ↑ Fracture toughness compared with Feldspathic - ↑ sintering linear shrinkage (12-20%!!). Need to compensate with an oversized die
Leucite-Based Ceramic (up to 45% leucite)	- ↑ Flexural strength and compressive strength vs Feldspathic - ↑ Thermal contraction coefficient (Expands and contracts lots with temp change) - Large mismatch in thermal contraction btwn leucite and glassy matrix -> acting as crack deflectors
Heat Pressed All-Ceramics	
Leucite-based (35-55%)	1st gen of heat-pressed ceramics - Can stain or veneer - 2x the flexural strength over feldspathics
Lithium Disilicate-Based (65% highly interlocking crystals)	4x the flexural strength of Feldspathics - Extended range of applications b/c of ↑ properties ↓ Esthetics = need a veneering porcelain *Indications*: Inlays/Onlays/Veneers, Single unit crowns, short-span anterior Fixed prostheses
Slip-Cast All-Ceramics	
Alumina Based (68% alumina) **Or** **Zirconia-toughened Alumina based** (34% alumina, 33% zirconia)	Very Very strong (b/c high density packing of alumina particles) -> 2x the Lithium Disilicate based Heat pressed! ↓ Esthetics (high opacity) and long processing times *Indications*: Single Unit crowns, short-span fixed partial Prostheses
Machinable All-Ceramics	
Hard Machining (post sintering)	*Possible for:* -Feldspar -Leucite -Lithium Disilicate ➔ Makes Crown fabrication possible in 1 visit ➔ Low to moderate strength -> Single Units only
Soft Machining followed by Sintering	Pre-sintered blocks are milled down into the crown: -Alumina, -Spinel or -Zirconia-toughened alumina ➔ Can get sintered Zirconia blocks as well but they are almost too hard to mill and cost $$$ Restorations are oversized to allow for shrinkage after sintering Have the highest flexural strength and highest fracture toughness of all - Problems with cracks at the interface between veneering porcelain and core ceramic though

Dental Cements

Cement = material that sets with an acid-base reaction

- Forms a solid used as liners, bases, luting agents or Intermediate restorations

Zinc Phosphate

Components	*Powder*: Zinc oxide + 10% magnesium oxide (to ↓ reactivity) *Liquid*: 45-64% aqueous phosphoric acid solution **Phosphoric acid is damaging to vital tissues -> Add coping varnish first to protect porous dentin (filtration)** *Filtration*: Liquid separates from powder when pushed down onto tooth -> compromises reaction and allows acid to penetrate dentinal tubules (sensitivity)
Indication	Cementation of metallic crowns and porcelain-fused to metal crowns/bridges - Cement itself is very weak, cannot rely of the strength of the cement to make ACC stronger. Crowns must be strong on their own (MCC, Zirconia-reinforced)
Advantages	Easy to mix (1.5mins) Sharp, well-defined set -> 3.5 min setting time Cheap
Disadvantages	Acid can damage/irritate the pulp No antibacterial action Brittle and weak No/very little adhesive properties Relatively soluble in oral environment

Polycarboxylate

- Largely replaced by GIC's now

Components	*Powder*: Zinc Oxide + 10% Magnesium Oxide *Liquid*: 30-40% aqueous polyacrylic acid - Can change mixing ratio to accommodate the application (thinner = luting, thicker = restorative) - Polyacrylic acid is less acidic than phosphoric acid, ↑ molecular weight/size makes it less likely to penetrate the dentinal tubules (↓ sensitivity) - ↑ MW makes it a stronger cement
Indication	Cementation of metallic crowns and porcelain-fused to metal crowns and bridges Temporary restorations
Advantages	Bond to enamel AND dentin AND some metallic casts - Polyacrylic component forms ionic bond to dental structure (Ca^{++}), still weak though ↓ irritancy to pulp Similar strength and solubility to Zinc Phosphate cements Have antibacterial properties
Disadvantages	- Properties dependant on handling procedures - Short working time but long setting time - Good technique is needed to ensure bonding - Binds to everything, makes cleanup challenging -> Cover outside of crown with Vaseline to prevent excess from binding to it

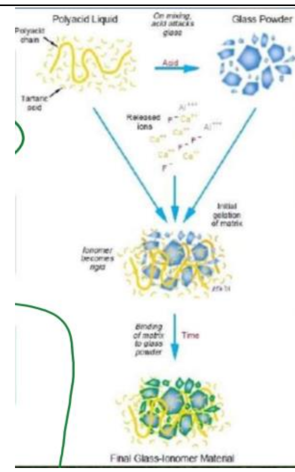
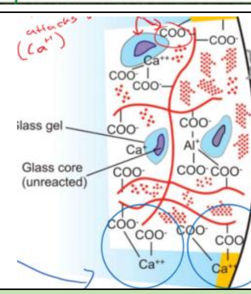
Zinc-Oxide Eugenol

****Compromises the curing of resin-based materials! -> Consider not using if going to do a composite filling as the permanent resto****

- This is temporary. After 1-2 weeks will be able to cure resin again. Replace Zinc-Oxide with a non-eugenol material for 2 weeks and then you can do the final resto in composite.

Indications	Lute crowns onto implant abutment - Weak cement, but works b/c crown-abutment is so tight it can be hard to remove if cement is too strong Intermediate fillings/temporary

Glass-Ionomer

Components	*Liquid:* - Polyalkenoic Acids (Acrylic, Maleic, Tricarboxylate) - Tartaric Acid -> ↑ working time, ↓ setting time, ↑ handling properties, ↓ viscosity, ↑ shelf life - Water *Powder:* - Silica - Alumina - Calcium Fluoride -> Controls speed of the reaction -> Releases fluoride to remineralize teeth, and antimicrobial action -> Recharges F- content
Setting Reaction	**Phase I -> Ion Leaching** - Polyacid extracts ions from the glass powder - Ca^{++} released from surface *Mixing*: Shiny, Sticky, Glossy - Use syringe to apply to avoid sticky shittiness **Phase II -> Hydrogel phase** - Ions cause the formation of polyacid matrix (crosslinks glass and polyacid chains) - Very sensitive to H_2O ↑/↓ = protect surface with varnish/vaseline to prevent premature cracking or disintegration *Setting Rxn:* 3-6mins -> Rigid and opaque **Phase III (polysalt gel)** - Silica gel forms and attaches powder to matrix *Maturation*: 24hrs-1yr, forms tooth-like colour 
Bonding to Dental tissues	When polyacrylic acid attacks the glass powder to release Ca^{++} it also attacks the tooth structure to form ionic bond with Ca^{++} - Setting reaction and bonding reaction occurs at the same time -> Critical Period, do not disturb Takes up to 24 hours for bonding maturation to finish. - Delay or keep occlusal adjustments and finishing to a minimum to not disturb bond *Ionic bond strength of GIC is ↓ ↓ than Resin Composite micromechanical bonding, but seal is much better* 
Advantages	- Adhesiveness - Biocompatibility - Fluoride release -> Excellent for anti-caries and remineralization - Marginal sealing - Radiopacity - Coefficient of thermal expansion -> Closest to dental structure = longer lasting despite weak bond - ↑ modulus of elasticity -> Acts as a stress relieve layer - Bonds to metal! - Best material for a liner -> Releaves shrinkage stress along pulpal floor

<u>Classifications of GIC</u>

Composition	
Conventional	Typical Acid-Base reaction (Powder+liquid)
Metal Reinforced	Silver alloy incorporated - ↑ Strength
Resin Modified	Water-soluble methacrylate-based monomers replace some of the liquid component of GIC (acid chains) - Allows light curing
High Viscosity	Smaller glass particles and ↑ Powder /Liquid ratio than conventional GIC - ↑ Strength, took over metal reinforced - Small particles, means you can add more of them (↑ ratio)

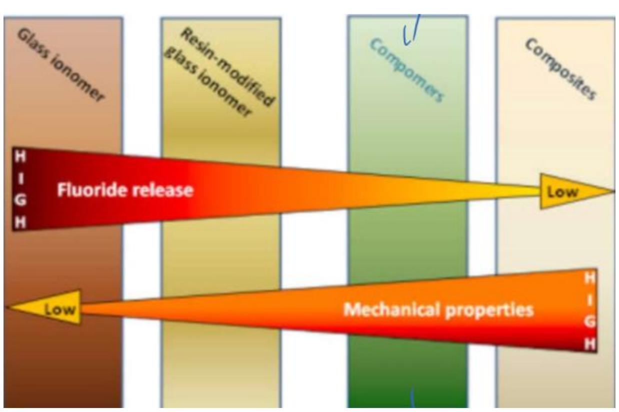
Indication		
Type I	**Luting Cement**	Luting crowns, bridges, orthodontic brackets
Type II	**A: Esthetic restorative**	Restorations - Type II's (A and B) have ↓ F^- but ↑ esthetics)
	B: Reinforced Restorative	Core build-up, ART
Type III	**Lining Cement or Sealant**	Liner, Sealant - ↑ F^- but looks like shit

Resin Modified Glass Ionomer

Composition	*<u>Powder</u>*: Fluoraluminosilicate (FAS) Glass - Initiator: Light and/or Chemical *<u>Liquid</u>*: HEMA (Primer) + Polyacrylic Acid modified with Methacrylate (polymerizable Monomer)
Curing Reaction	2 Reactions: - Free-Radical Polymerization (light curing) - Traditional Acid-Base Cure (although must slower than traditional GIC)
Advantages	- Can control when to cure (↑ working time) - Fluoride Release/ Uptake -> Excellent for anti-caries and remineralization/Adhesiveness - Biocompatibility - Radiopacity (probably some of the others from GIC?)

** True GIC's -> Acid-Base setting mechanism but provide at least 50% of expected max of structural properties after light cure**

- If not, it is not a GIC (or RMGIC) but rather a Compomer (lowsy composite, useless for anything)



Material	Compressive strength (MPa)	Diametral tensile strength (MPa)
Type II - conventional	196-251	18-26
Type II – resin modified	202-306	20-48
Cermet	176-212	19-22
High-viscosity	301	24

Dental Resin Cements

= Low-viscosity version of restorative resin composite. Pretty much the same thing but with a ↓ filler/monomer ratio

- Diluted Resin Composite

Another option for cementation:

<u> The cement of choice for all-ceramic based and composite-based indirect resto's!**</u>**

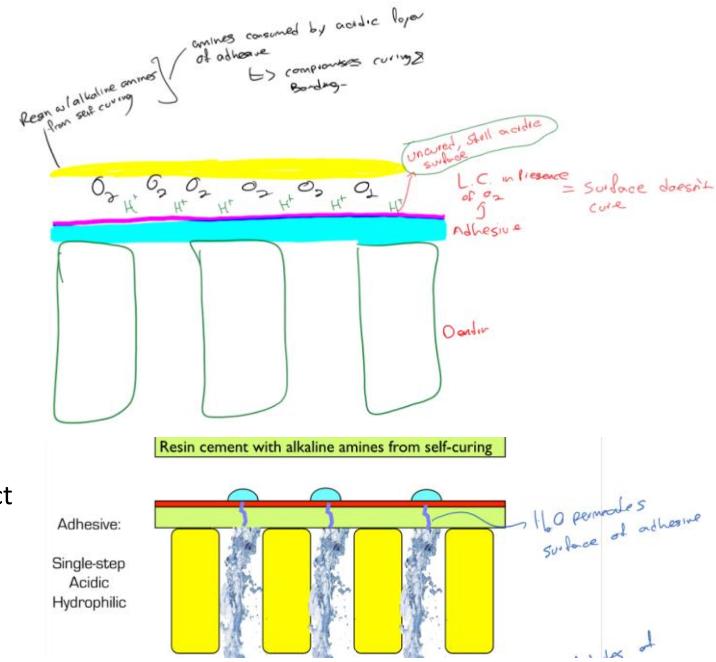
- Have the ability to bond both to the tooth structure and the restoration (Still need adhesive agent and pre-treatment though)

<u>Classifications:</u>

	Curing Type
Self-Cured	Sets via self-curing only -> NO Light curing needed - Takes 3-5mins - Limited working time, and delayed adjustments (have to wait till cured fully) *<u>Indications:</u>* - Cementing any indirect resto's (Metal, ceramic, metal-ceramic, composite) **Can't be used in combination with some simplified, acidic hydrophilic adhesives**
Light-Cured	Sets via light curing only - No tertiary amines -> superior colour stability over time (that's why it's good for veneers, they won't yellow over time) - Comes in a variety of colours to match the veneer *<u>Indications</u>*: Cementing laminate veneers - (only thing thin enough for light to pass through during the curing)
Dual Cured **- Most popular**	Sets via both self-cure and light-cure - Light cure is needed for it to achieve maximum strength *<u>Indications</u>*: - All-ceramics and composite indirect restorations **Can't be used with some simplified acidic hydrophilic adhesives**
	Adhesion Type
Non-Adhesive	Requires application of bonding agent (adhesive) prior to cementation - Tooth substrate must be treated w/adhesive (**<u>Etch & Rinse or Self-Etch</u>**) **<u>Self-Etch Adhesive</u>** - Have to apply primer first prior to cementation (primer is a bonding agent)-> considered a non-adhesive
Self-Adhesive	NO bonding agent application required prior to cementation - ↓ bond strength vs non-adhesive cements (↓ microporosities = ↓ micromechanical retention) Tooth must be cleaned of temporary cements before cementation - Don't overdry, keep surface moist Initial low pH of the self etching acidic monomers must be neutralized by tooth structure and filler particles before curing -> Acid residue will compromise curing/polymerization - Doesn't work with metals or core build up materials -> won't neutralize = ↑ hydrophilicity after curing H_2O will compromise bond **<u>Steps</u>**: 1. Clean prep -> leave surface moist, do not overdry with air! 2. Apply Self-adhesive resin cement 3. Seat crown -> do not light cure right away. 4. Allow 1-2 minutes to ensure acid has been neutralized sufficiently 5. Remove excess 6. Light cure from all faces of resto.

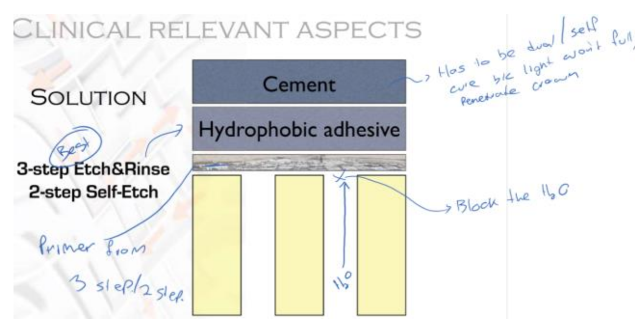
Why are acidic monomers not always compatible with Dual or Self-Cured Resin Cements?

- Single-Step, simplified adhesives contains acidic monomers
- The adhesive in contact with the tooth structure becomes sufficiently neutralized, but on the surface of the adhesive layer there are still acidic monomers within the uncured O_2 inhibited layer
    - These consume amines in the Resin Cement that promote the self-curing.
    - Under-cured cement at the Adhesive-Cement interface = weak bond
- Acidic monomers are also hydrophilic (attract water)
    - Water from within the dentinal tubules can penetrate the adhesive layer in order to interact with the uncured acidic monomers
    - Compromises bond further



How do solve the problem:

- Don't be a fool! Use the 3 step (Etch-Prime-Bind) or 2 Step Self Etch!
- By adding an extra layer of primer under the adhesive, it will block the water from the tubules from penetrating and compromising the bonding between the adhesive and the cement

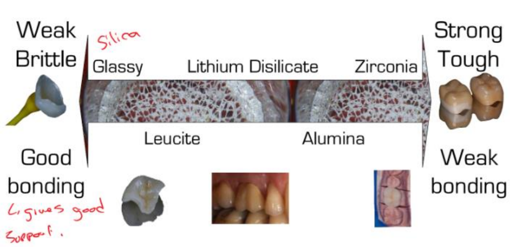


Bonding to Ceramics

Why is bonding important for the success of ceramic restorations?

1. ***Additional Retention***
    - Never rely on the bonding completely for retention though. Frictional retention from a well-designed prep is far stronger
2. ***Marginal Sealing***
3. *****Functional Support*****
    - This is the most important factor
    - Ceramic is very brittle, will break if directly sitting on a compliant/flexible tooth. Additional layer of bonding gives support and acts a stress reducing layer.

Bonding treatment will depend on the ceramic composition and structure:

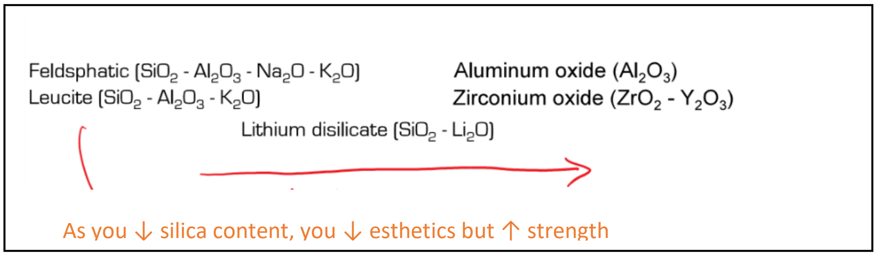


Silica-containing ceramics (Feldspar/Glassy, Leucite, Lithium Disilicate) can be etched with HF acid and silanized.

- Silica is the etched component + silanization allows ↑ chemical bonding to adhesive

Non-Silica containing ceramics (like Zirconia) cannot be acid etched because no silica

- Sandblast etched instead + use MDP (acidic self-etching monomers) -> chemically bond to zirconia.



Strength of the crown depends on:

Type of Ceramic	Feldspathic and Glassy are the weakest -> fine for anteriors that don't have major occlusal loads. Wouldn't use for posteriors though
Characteristics of Core/supporting structure	Modulus of Elasticity of cement is important - ↑ E of the luting cements = ↑ hardness -> better to ↑ success of crown. - Self Adhesive resin cements absorb ↑ H_2O b/c of hydrophilic acidic monomer -> Makes it softer and not ideal for cementing cements **Best cement = Non-adhesive cement with 3 step or 2 step etch and rinse**
Type of material and Thickness of the crown	Quality of curing depends on crown type and curing mode - Metal ceramic crown won't let light through for curing -> Zirconia and Lithium disilicate ↑ degree of monomer conversion - **Dual Cure cements are best** -> LC from all 3 surfaces (B,L,O) and let self cure take care of the rest.
Bonding Technique	Explained below for Glassy, Lithium Disilicate, and Zirconia, Lab processed composites

Techniques (Glassy Veneers)

1. **Sandy Blasting (<10sec, 20psi)**

After firing process there are residues left of the surface. -> Sandblasting cleans the surface and removes the residues, exposing the porosity within the structure

2. **HF Acid Etching (9-10% HF acid, 90 sec)**

Etches the silica particles only to ↑ the porosity

- It if looks like it has been *over etched* (F^-salts precipitating on surface)
  -> Ultrasonicate in ethanol for 5 mins, dry well with air. This removes the F^- based salt that forms on the surface as a contaminant

  -> *If you can't ultrasonicate with ethanol* = Etch surface with phosphoric acid for 10 sec. rinse and dry (same as you would do for enamel)

3. **Silanization (1-2 THIN coats of silane with microbrush, dry with warm air 60sec)**

Creates a chemical bond with the tooth structure:

- Condensation reaction occurs -> -OH from surface + -OH from Silane = Covalent bond (strong!) + H_2O

Use warm air to dry and evaporate the H_2O before binding the adhesive

- Surface SHOULD appear dull -> if it looks shiny = excess silane (no Bueno). Start over from sandblasting step

The 1st bond between the Si and Ceramic is one of the strongest we can get (covalent) -> the 2nd layer of Si is terrible though! = Need to remove the excess

- Can place in boiling water for 10 minutes and excess silane should come off, but its more efficient to just sandblast and etch again

Recommended to silanize as soon as you get it from the lab and try it in. Excess Si might just rub off when you try it in

<u>To avoid contamination, its best to have it sandblasted at the lab and you do the HF and silanization yourself**</u>**

<u>Silane Primers</u>	
Single Bottle System	**2 Bottle System**
<u>Pros:</u> - Easy to use (no mixing required) **<u>Cons:</u>** - Limited Shelf Life (its already activated) -> if it comes out not clear/transparent = expired	1 Bottle is Acetic Acid Activator, the other bottle is unactivated silane **<u>Pros:</u>** - Longer shelf life, stable because they arnt mixed yet **<u>Cons:</u>** - You need to mix the 2 components

4. **<u>Cementation</u>**

3 Step Etch and Rinse or 2 Step Self-etch priming needed to prevent H_2O contamination -> Universals wont work (same reason as we saw in resin cements)

Apply HEMA-Free (HEMA yellow's) bonding agent -> Bis-GMA based ideally

- Porosities created are small, and cement molecules are large, so you need to really ↓ the viscosity of the bonding agent the fill the pores -> Micromechanical retention

Because these are veneers we want a cement that will not change color/yellow over time

-> Light Curing, or Aromatic Amine-free dual cure resin cement

Technique – Lithium Disilicate based Ceramic

- Same as glassy except using 5% HF acid for only 20 seconds
  - Less silica = less acid for less time

Technique - Zirconia

Because there is no silica in this material neither HF etching nor silanization is possible.

- Combination of *mechanical and chemical treatment* used.

1. **Sandblast surface**

Done with ↓ pressure and time than glassy ceramics (considered a soft sandblast)

- 3M has a product called Rocatec Plus which sandblasts with silica particles to impregnate them into the surface of zirconia. -> $$$$$ though and it doesn't ↑ the success enough to make it worth it

2. **Apply Zirconia primer**

MDP self etching monomer/primer will bind to zirconia to ↑ bond strength (but still no where close to glassy ceramics)

3. **Apply MDP containing cement**

- (Resin cements are preferred, but other cements will work)

Because we used MDP monomers for the primer we should use an MDP compatible/containing resin cement

Technique – Lab-processed composites

Indirect Composite	Supporting tooth structure
1. Clean the surface 2. Sandblast with Aluminum oxide 3. Apply Silane	Cannot HF etch composites - Choose total-etch, self-etch or self-adhesive systems.

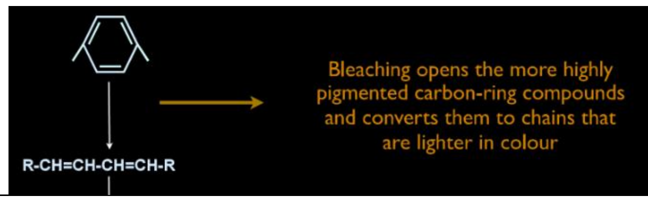
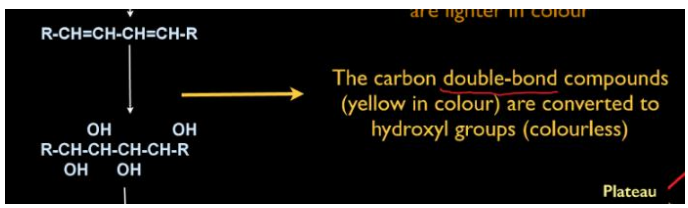
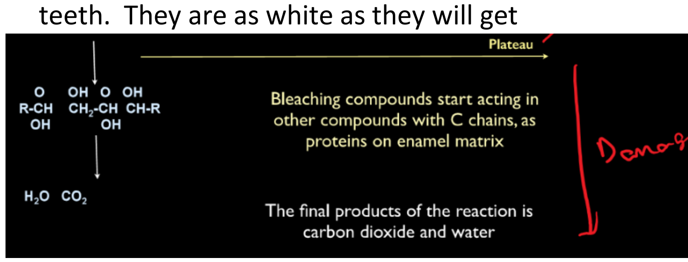
Bleaching

Mechanism of Action

Delivering Hydrogen Peroxide (the active ingredient) to discolored segments of the tooth into order to dislodge discoloring particles

Hydrogen Peroxide (H_2O_2)	Carbamide Peroxide ($CH_6N_2O_3$)	Sodium Perborate ($NaBO_3$) - For endodontically treated teeth
1%, 3%, 10%	When in contact with H_2O will break down into Hydrogen Peroxide (33% + urea) - This means 1/3rd of the % of Carbamide Peroxide will become Hydrogen Peroxide Ex: 21% Carbamide Peroxide = 7% Hydrogen Peroxide	When contacts H_2O breaks down into hydrogen peroxide (22-34%) - Only ¼ - 1/3rd will become hydrogen Peroxide

So whats happening?

Step 1: Diffusion - H_2O_2 Penetrates tooth structure	Hydrogen peroxide easily diffuses through organic matrix of the enamel and dentin b/c of its low MW - Similar flow pattern to fluids in the inter-prismatic spaces of enamel and dentinal tubules *Diffusion can be ↑ by:* - ↑ Concentration - Prolonged application - ↑ Temp - Larger tubules (like in kids) - Variation of tooth structure
Step 2: Interaction - ROS Attack	Free Reactive Oxygen Species attack organic molecule chromophores in order to become stable - Highly pigmented carbon-ring are opened into chains Rate of decomposition depends on **Temp and concentration** 
Step 3: Surface and colour change - Simplifying Molecules	Radicals disrupt organic molecules to make them simpler -> Reflect less light making them appear lighter in shade Carbon double bonds are converted into colourless hydroxyl groups 
Step 4: Plateau	This cycle continues until all the original pigment is colourless and a plateau phase is reached (no longer notice color change) - Stop the bleaching at this phase, continuing will do nothing but damage the teeth. They are as white as they will get  Can start to see morphological alteration (deproteinization, demineralization, oxidation of superficial enamel layer) -> ↑ roughness and surface irregularities

Endodontically Treated Teeth

Typically, the stain will come from within the treated canal. -> Have to do internal bleaching

Step 1: Remove the pigment lining the pulp chamber	
Step 2: Seal the bottom of the pulp chamber and dentin to prevent peroxide from penetrating	
Step 3: Apply Sodium Perborate to change the color from the inside of the tooth	

Before

------------------------------→

After

Supervised At-Home Therapy

Carbamide Peroxide is the main product used:

w/ Potassium Nitrate and Fluoride Desensitizing gel	w/o Desensitizing gel
- 10% (3% Hydrogen Peroxide) - 15% (5% HP) - 20% (7.5% HP)	- 10% (3% HP) Only

Technique:

Record baseline shade - Helps monitor progress	 A3 in this case
Custom tray is made for the patients' teeth	- Apply CP gel on the vestibular (facial) surface of the tray - Apply for 2-hour intervals -> Overnight or during the day…will only be doing something for 2hrs though With low concentrations (like 10% CP) it can be applied up to 3x a day! - ↑ concentration, ↓ applications 
Schedule Weekly follow-ups - Follow shade progression	 When plateau is reached, and shade is no longer changing, **stop therapy**

In Office Therapy

Solutions can be way more concentrated for in-office treatments

Hydrogen Peroxide Straight Up	Carbamide Peroxide w/ desensitizing gel (potassium nitrate and fluoride)	Carbamide Peroxide
- 35-38%	- 35% (12% HP)	- 45% (15% HP)

Ensure good rubber dam Isolation - Traditional, or use a light cured gingival barrier resin gel (paint on dam)	 	High concentrations of HP will burn soft tissues, must be very careful
Paint on Hydrogen Peroxide, or Carbamide Peroxide		- Coloured at first, but will become colorless to indicate the reaction is over - Younger patients have more permeable teeth -> ↑ chance of developing sensitivity - Desensitizing gels interrupt the neurosensorial response in the teeth to ↓ sensitivity

Don't inject Local anesthetic when bleaching -> Need to know if the patient is feeling sensitivity so we don't cause major damage

In-Office treatments are convenient (only 1x 30-60 minute appointment can achieve the results a patient wants in 1 day vs weeks

- HOWEVER, the fact that sensitivity is developed means we are pushing the boundaries with such high concentrations of HP
- It has been shown that lower HP concentrations (20%) are JUST as effective than 35-40% HP gels -> not worth it for the extra %
- It has also been shown that at home treatment is equally effective with ↓ sensitivity (because % lower).
  - -> This method is safer, more convenient for the patient (@ home) but takes longer
- In Office treatment should be reserved for last minute urgent whitening cases. Can finish the job at home though

Over the Counter Bleaching

One Size fits all trays	↑ risk of soft tissue burning
↑ Risk of damage to teeth	No supervision of shade changing, or plateau phase
Straight up dangerous	Unregulated unsafe ↑ concentrations of HP available online

Oral Effects of Peroxides

Soft Tissue	HP >15% can burn soft tissues - Protect with rubber dam or well adapted custom tray Using neutralizing agent (Sodium Bicarbonate) to ↓ extent of damage FDA says HP is safe in concentrations up to 3% -> Many untrained amateurs dealing with higher concentrations at home!
Toxicology	Body has endogenous enzymes for battling HP: - Catalase - Superoxide Dismutase (SOD) - Peroxidase
Carcinogenicity	No evidence of carcinogenicity 😉 - 1 group in the 80's scared everyone by saying there was, they were wrong
Enamel	<u>Effects on Enamel:</u> ↓ organic content Exposure of enamel prisms ↓ hardness ↑ surface porosities *Lots of bad effects, so we have to control concentration, application time and pH closely - CP gels don't have a low pH (5.6-7.3) and Urea ↑ pH further -> the pores that form are not from CP but from a disruption of enamel protein matrix and loss of crystalline material around this matrix
Dentin	**HIGHLY CONTRAINDICATED** - Dentin has ↑ susceptibility to HP oxidation and acidic pH of the gels = immediate sensitivity
Pulpal Responsiveness	Hypersensitivity: - Varies with each patient from slight to intolerable - If patient is ALREADY sensitive to temps -> MAX 10% CP 1x/day - HP can reach the pulp tissues leading to oxidative cell damage and local inflammation - keep concentrations low

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Amalgam

= Alloy containing: ***Mercury, Silver, Tin, and Copper*** ->May also contain zinc and palladium

Trituration – Mechanical mixing of amalgam alloy with mercury

Amalgamation – Reaction of mercury with amalgam alloy to form amalgam

Clinical Application

- Used for Class I and Class II restorations (other classes would not be able to create a retentive form that would hold amalgam)

Creep	Solid material slowly deforming plastically under influence of static load ○ Causes amalgam material to flow over the margins over time, leading to fracture, ditching. - Correlates with marginal breakdown of low-copper amalgams (Gamma-2 phase)
Tarnish	Discolouration of amalgam, does not affect the mechanical properties
Corrosion	Gradual destruction of material by electrochemical reaction. - Negative effects on the mechanical properties, but increases marginal sealing as the corrosion creates expansion of the amalgam Gamma-2 phase actively corrodes -> in high copper allows corrosion is more limited

<u>3 mixtures:</u>

	Fast Set	**Regular Set**	**Slow Set**
Condensing time	2.5 minutes	3 minutes	4 minutes
Carving Time	4.5 minutes	6 minutes	6 minutes
Total Time	7 minutes	9 minutes	10 minutes

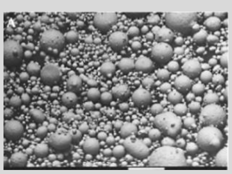
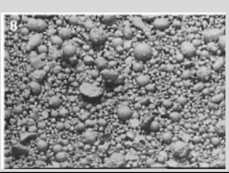
Alloys

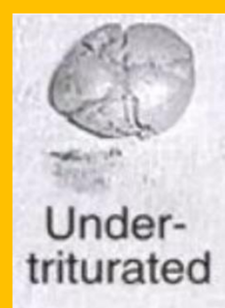
Basic Constituents: *__Tin__* (Sn), *__Silver__* (Ag), *__Copper__* (Cu)

Other Elements: Zinc (Zn), Palladium (Pd), Indium (In)

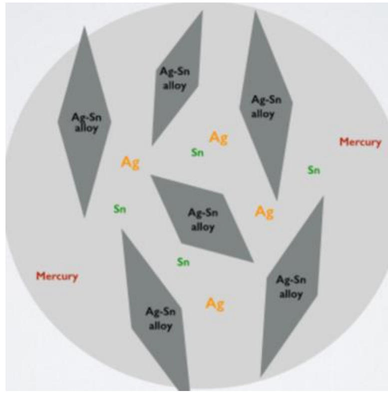
- If >0.01% Zn it is considered a "Zinc containing alloy"

Low-Copper Alloys				
	Silver	**Tin**	**Copper**	**Zinc**
Percentage	63-70%	26-28%	2-5%	0-2%
Properties	Increases Strength Increases Expansion	Decreases Expansion Decreases Strength Increases Setting Time	Reduces Gamma-2 Increases Strength Reduces corrosion Reduces Creep	* Byproduct from manufacturing process Decreases Oxidation during manufacture Delayed expansion of amalgam if present in condensation
Other Random components	**Indium (In)** - ↓ amount of Hg - ↓ creep and marginal breakdown - ↑ Strength (in admixed alloys)		**Palladium (Pd)** - ↑ Corrosion - ↑ Luster	

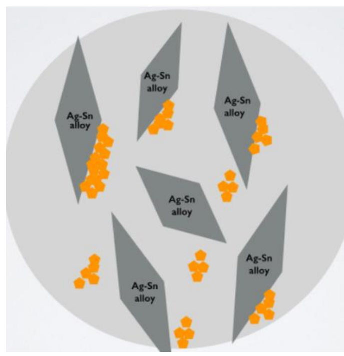
Shape	Properties
Lathe-cut 	Alloy made into ingot and filings cut off on a lathe and ball-mill Resists compression more - Needs ↑ pressure Size Ranges: Length: 60-120um Width: 10-70um Thickness: 10-35um
Spherical 	Alloy atomized into fine drops in chamber of inert gas Increased plasticity, and less pressure required for condensation Diameter: 2-43um - **Smaller molecules ↑ surface area, need ↑ Hg, harden faster**
Admixed 	Combination of spherical and lathe-cut Middle ground between Lathe-cut and spherical Need ↑ pressure to condense

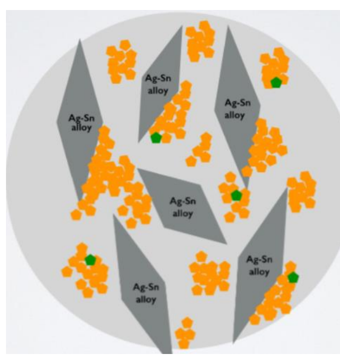
Trituration	
Under triturated	Over triturated
-Grainy mixture -Poor plasticity -Non-Uniform Hg Distribution -Weak Amalgam -Rough surface after carving - Higher susceptibility to tarnish 	-Softer mushy mix -Sticks to capsule walls -Shinier surface -Short working time 

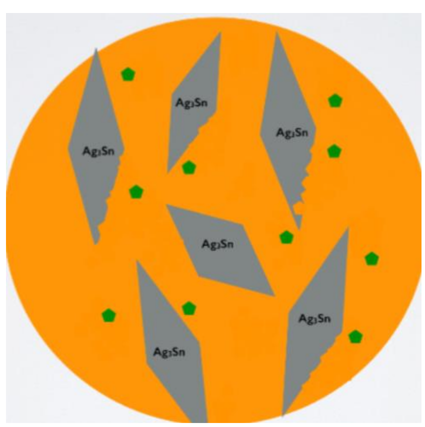
Alloy Setting

<table>
<tr><th colspan="3">Low Copper Amalgam (<6%)</th></tr>
<tr><th>Step</th><th>Visual</th><th>What is Happening</th></tr>
<tr><td>$Ag_3Sn + Hg \rightarrow Ag_3Sn + Hg + Sn + Ag$</td><td>
</td><td>Gamma (Ag_3Sn) and Mercury (Hg) are present in 1:1 ratio

Hg dissolves some Ag and Sn from the alloy
- There is still undissolved alloy present. Forms core amalgam.

What do we have:
Alloy, Hg, Sn, Ag</td></tr>
<tr><td>$Ag_3Sn + Hg \rightarrow Ag_3Sn + Ag_2Hg_3$</td><td>
</td><td>Ag_2Hg_3 (Gamma-1) begins to precipitate out first.
- Will form the "glue" that holds together the Alloy particles.

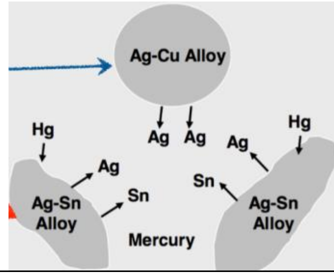
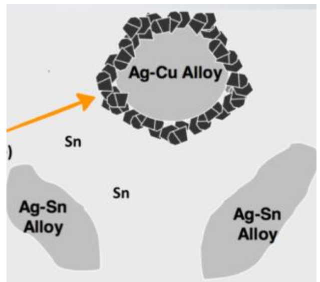
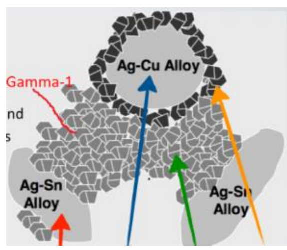
<u>What do we have:</u>
Gamma, Ag_2Hg_3</td></tr>
<tr><td>$Ag_3Sn + Hg \rightarrow Ag_3Sn + Ag_2Hg_3 + Sn_8Hg$</td><td>

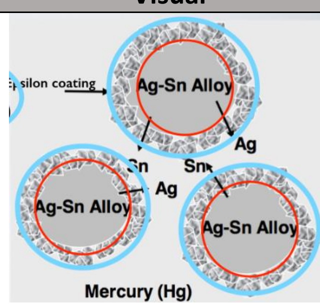
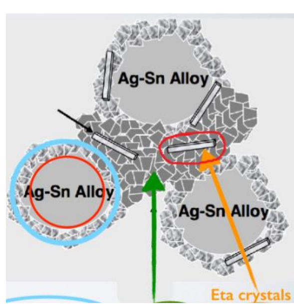

</td><td>Sn_8Hg (Gamma-2) precipitates out second.
- These are contaminants that create voids in the gamma-1 glue, decreasing the strength.
- Weakest phase
- Most prone for corrosion

Ag_2Hg_3 (Gamma-1) continues to precipitate and fill the spaces between allow particles.

Ag_3Sn (Gamma) is the strongest phase.

<u>What do we have:</u>
Gamma, Ag_2Hg_3, Sn_8Hg</td></tr>
</table>

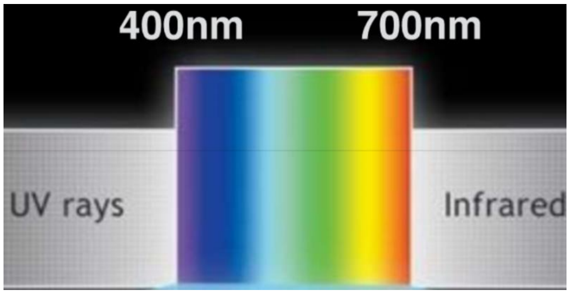
High Copper Amalgam (Admixed)		
Step	**Visual**	**What is Happening**
Ag_3Sn + AgCu + Hg		Ratio is 2:1 Lathe-cut Ag_3Sn to spherical AgCu Hg dissolves Ag and Sn out of the Gamma (Ag_3Sn) alloy, and Ag out of the AgCu alloy
Sn + AgCu -> Cu_6Sn_5		Instead of precipitating with Hg to form Gamma-2, Sn diffuses to react with AgCu particles forming: - Cu_6Sn_5 (Eta phase) - This eliminates the undesirable Gamma-2 phase
Ag_3Sn + AgCu +Hg -> Ag_3Sn + AgCu +Ag_2Hg_3 + Cu_6Sn_5		Ag_2Hg_3 (Gamma-1) precipitates out and forms the glue between Cu_6Sn_5 (Eta), AgCu and Ag_3Sn (Gamma) - No Gamma-2 phase is formed creating a stronger amalgam product

High Copper Amalgam (Unicompositional)		
Step	**Visual**	**What is Happening**
Ag_3Sn + Hg + Cu_3Sn		Hg dissolves Ag_3Sn into Ag and Sn. Ag_3Sn is surrounded by Cu_3Sn (Epsilon) coating Have to work gently to preserve epsilon coating.
Ag_3Sn + Hg + Cu_3Sn -> Ag_3Sn + Cu_3Sn + Ag_2Hg_3 + Cu_6Sn_5		Ag reacts with Hg to form Gamma-1 (Ag_2Hg_3) glue. Sn reacts with Epsilon phase (Cu_3Sn) to form Eta crystals (Cu_6Sn_5). - Preventing Gamma-2 phase from forming Left over Gamma (Ag_3Sn) contributes most of the strength of the compound

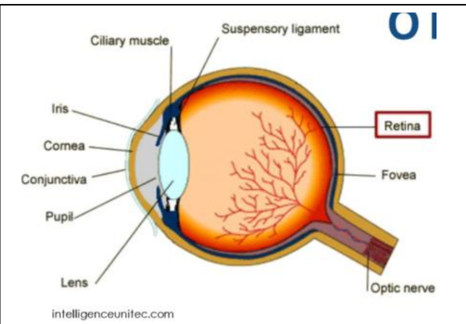
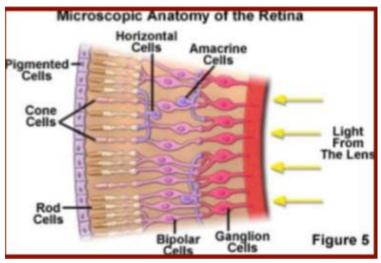
Trituration = Removal of oxide coating from alloy wets the alloy with mercury initiating the setting reaction.

Optics and Colour

Visible Light spectrum: 400nm -> 700nm



Retina in our eyes house different types of cells used to perceive light and colour:

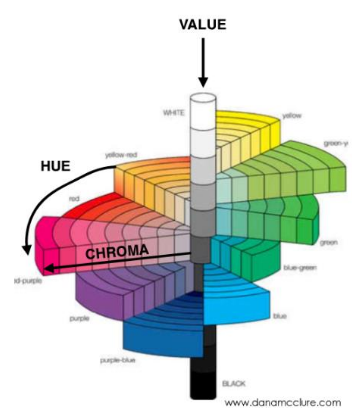
<table>
<tr><td>Rods</td><td>Perceive lightness and darkness</td><td rowspan="2">
</td></tr>
<tr><td>Cones</td><td>Perceive colour/hue
- 3 types to detect: Red, Blue, Green

</td></tr>
</table>

Colour

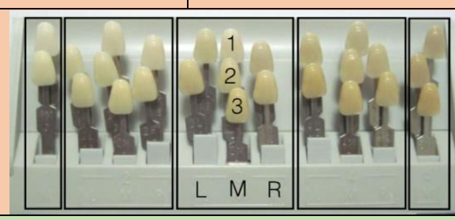
We perceive colour based on what is reflected off of the object and back at our eyes:

- White object: Everything is reflected back
- Black Object: Everything is absorbed and nothing is reflected back
- Red Object: Every wavelength is absorbed EXCEPT the red

Colour has 3 dimensions:

<table>
<tr><td>Hue</td><td>The name of the colour (Red, Blue, Green, Brown, Yellow etc)</td><td rowspan="3">
</td></tr>
<tr><td>Chroma</td><td>Describes the saturation of the colour (HOW green it is)</td></tr>
<tr><td>Value</td><td>Increases from black to white and refers to the lightness or darkness of the hue</td></tr>
</table>

Dental Shade Guides

<table>
<tr>
<td rowspan="1">Vita Classic</td>
<td colspan="2">Hue:
A - Orange
B – Yellow
C – Yellow/grey
D – Orange/grey</td>
<td>Chroma/Value
1 – Least Chromatic, Highest Value
2-
3-
4 – Most Chromatic, Lowest Value</td>
</tr>
<tr>
<td></td>
<td colspan="3">
</td>
</tr>
<tr>
<td rowspan="2">Vita 3D Master</td>
<td><u>Number -> Value</u>
1 = 2 tabs (Lightest)
2 = 7 tabs
3 = 7 tabs
4 = 7 tabs
5 = 7 tabs
6 = 7 tabs
7 = 3 tabs (Darkest)</td>
<td><u>Letter -> Hue</u>
L = Left (Yellowish)
M = Middle (Middle Hue)
R = Right (Reddish)</td>
<td><u>Number -> Chroma</u>
1 – Low chroma
2 – Middle Chroma
3 – High Chroma</td>
</tr>
<tr>
<td colspan="3">
</td>
</tr>
<tr>
<td>Spectrophotometers /Colorimeters</td>
<td colspan="3">↑ Accurate
↑ Precise
Easily reproducible numbers, easy to document, No influence of surroundings and lighting</td>
</tr>
</table>