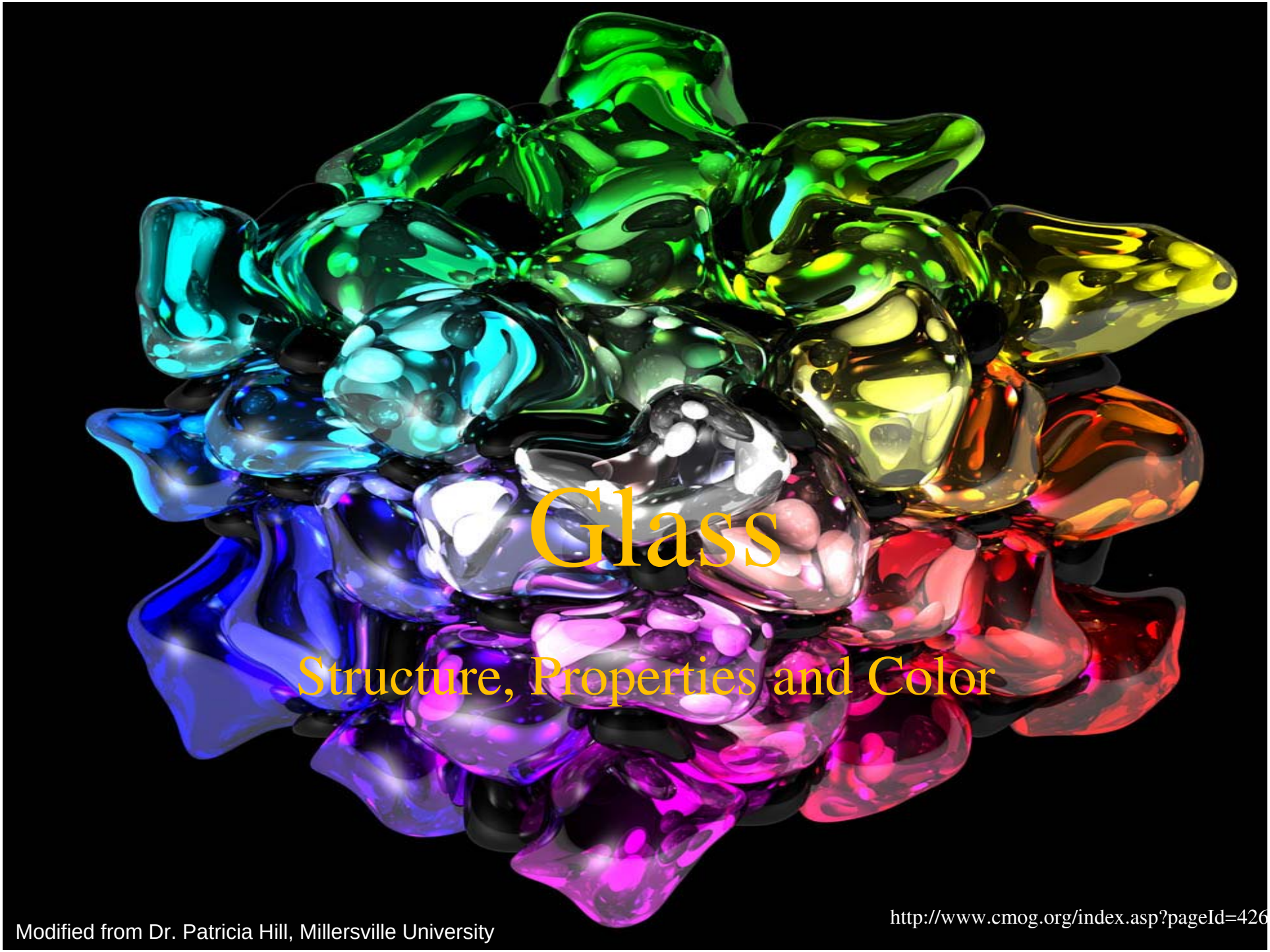
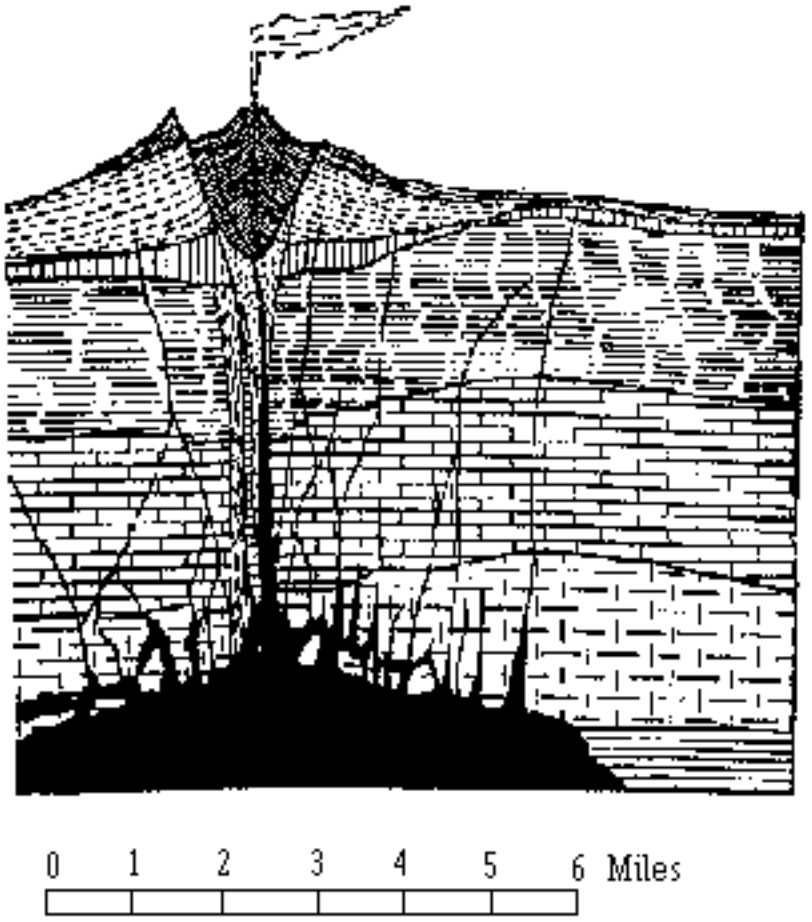


Modified from Dr. Patricia Hill, Millersville University

http://www.cmog.org/index.asp?pageId=426

Nature's Glass



Obsidian

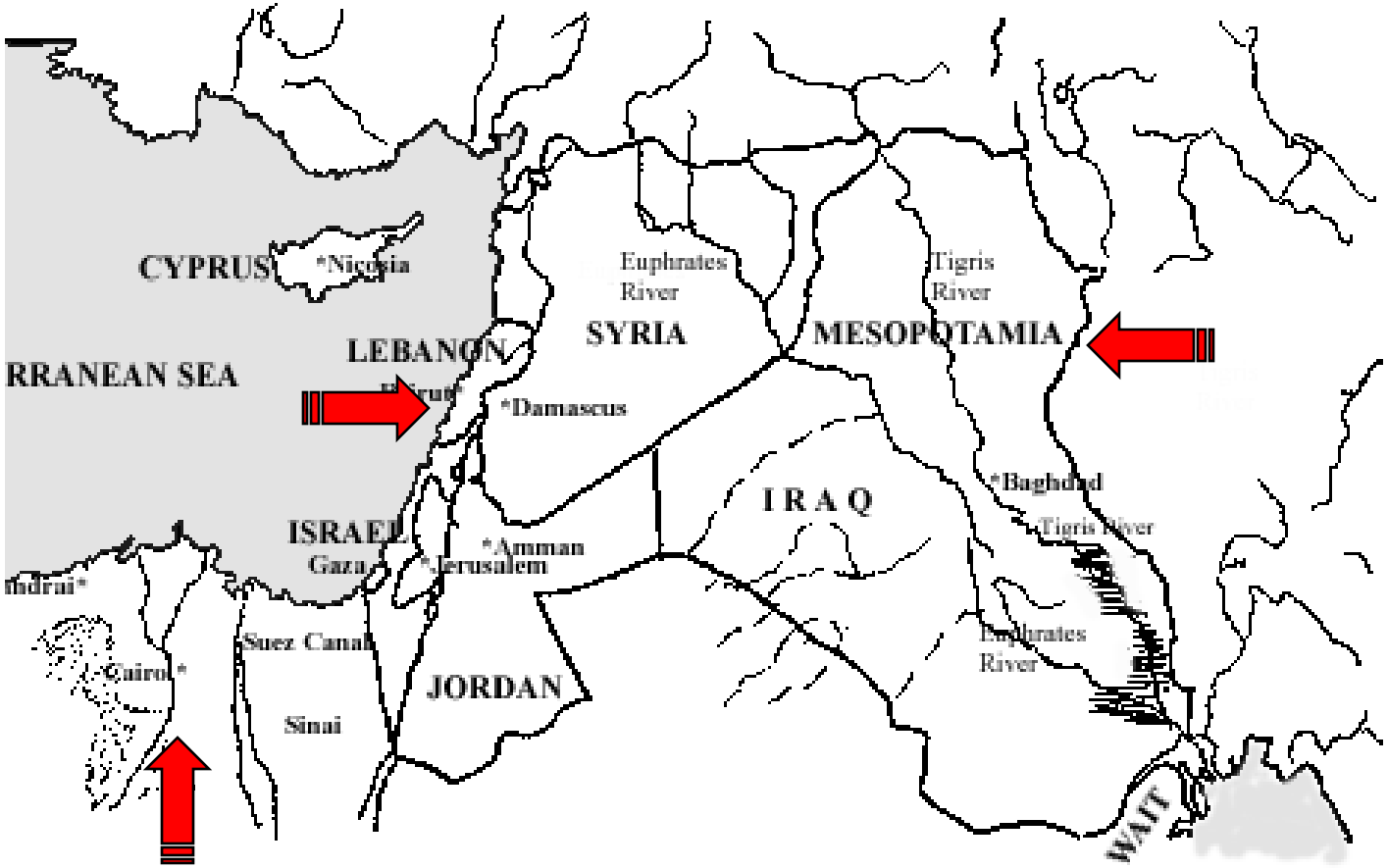
First used 75,000 B.C. for tools and weapons

Discovery of Glassmaking

- Phoenicia or Mesopotamia (modern day Lebanon, Iraq and Syria)
- ~4,000 B.C.
- Possibly an accidental discovery — heating of sand, lime and natron
- May have been observed as a by-product of metallurgy

Illustration from "Story of Glass Coloring Book" ISBN 01486-24199-8 courtesys of Dover Publications, Incorporated

Birthplace of Glassmaking



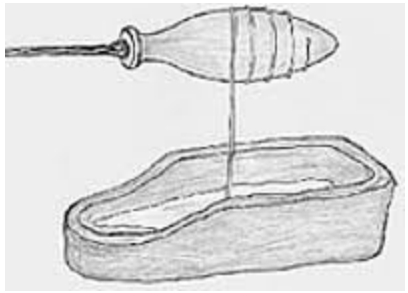
Egyptians developed the art.

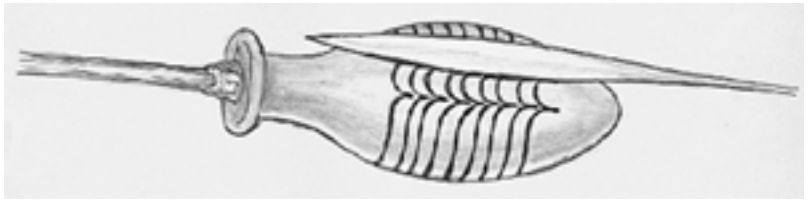
Early Glassmaking Methods

- Egyptians developed several methods for making beads and vessels with glass
  - Beadmaking
  - Casting
  - Core forming
- Slow methods

Wound glass beads, Iran, 1st millennium B.C.

Core forming





Core-formed fish vessel, Egypt, 1353-1336 B.C.

Core-formed vessel
Egypt, 1360-1240 B.C.
11.5 cm high

Core-formed Jar

- Egypt
- 1295-1186 B.C.

New, Faster Methods in 50 B.C.

- Romans and Phoenicians developed
  - Glassblowing
  - Multi-layered colored glass — *millefiori*
  - Glass carving

Millefiori Dish— 3rd century A.D. East London excavation

Blue Blown Flask— 5th Century A.D., Mediterranean

The Morgan Cup — Roman cameo Glass from 1st century A.D.

Blown Glass

- Roman glass from 750-550 B.C.

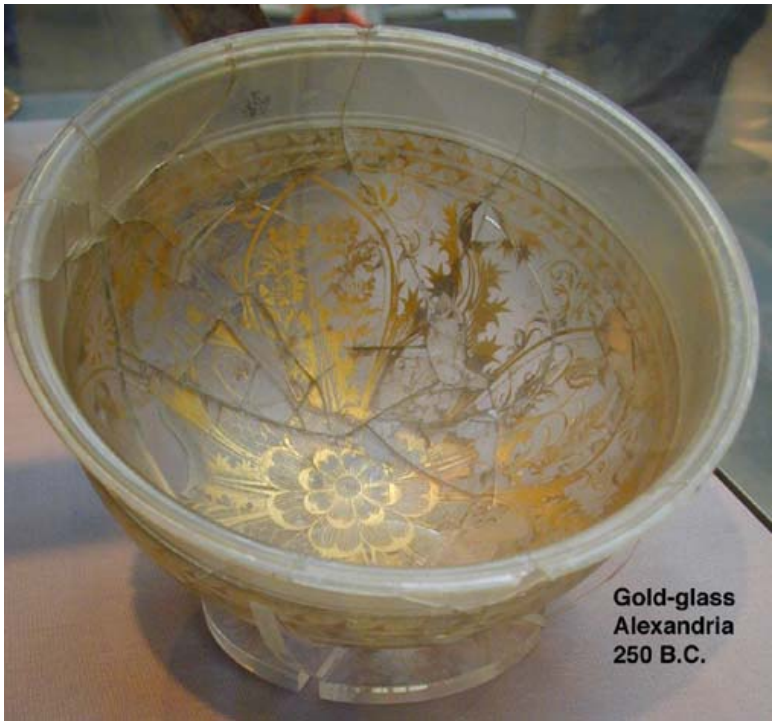
Blown glass jar (750-550 B.C.)

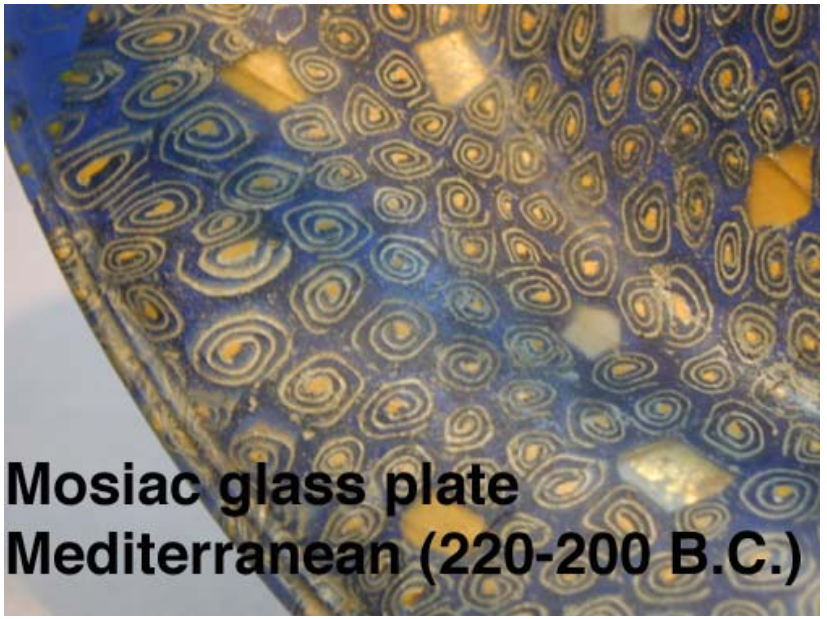
Roman Blown Glass

Glass perfume pot or oil flask. (London, 2nd Century A.D.)

Glass jug with chain handle (Essex, 3rd Century A.D.

Fancy Mediterranean Glass

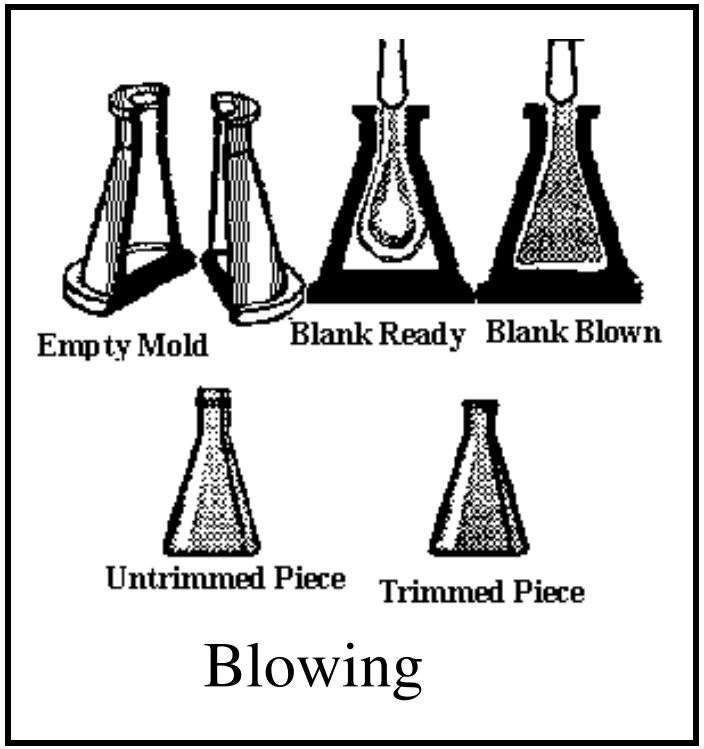


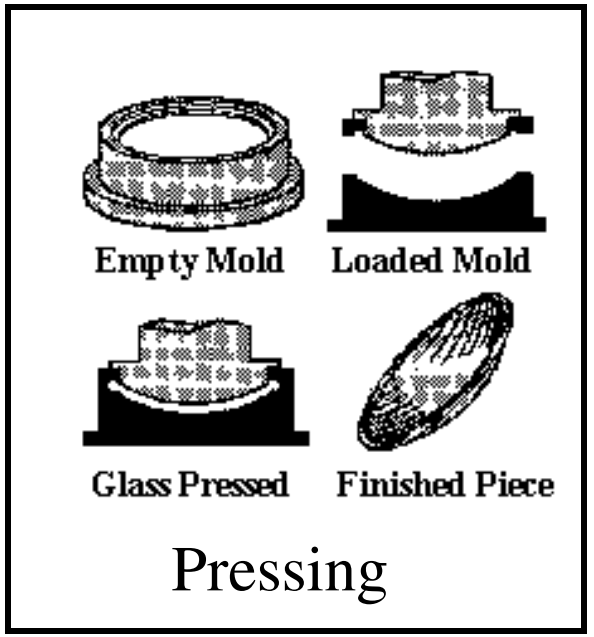


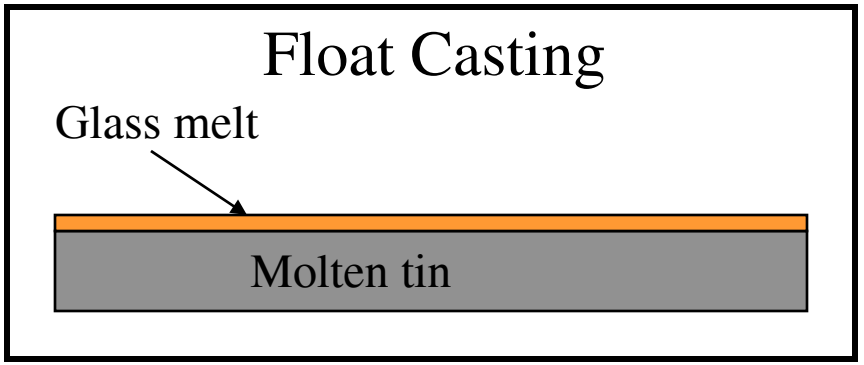
Venice —Glassmaking Center

- Renaissance13th - 15th centuries
- Secret techniques
- Glassmaking slowly spread to other European countries.
- brought to America in 1608

Modern Production Methods







Stained Glass

- Beginnings in 10-12th centuries
- Colored glass held together with lead strips
- Painted and fired to fuse paint to glass.

15th century roundel
Aesop's *Reynard the Fox*

Virgin Annunciate, 1340, Worcestershire, England

Painted Glass

- 2-3rd Century A.D.
- The Yorks

Reims Cathedral (French 1211A.D.)

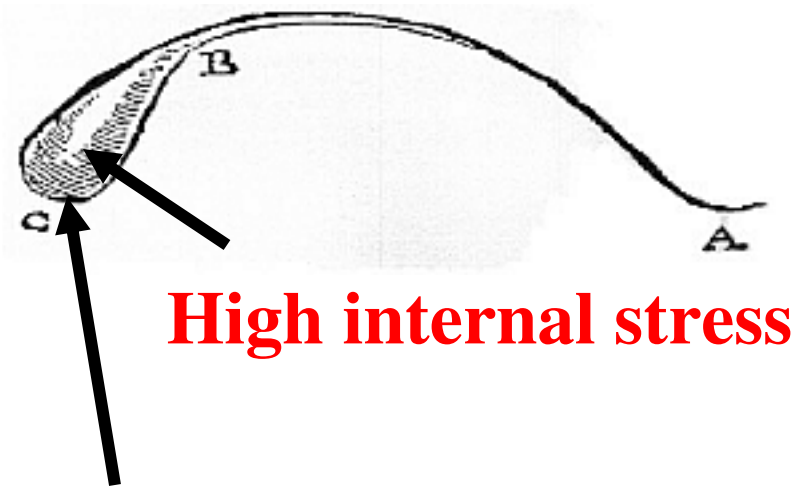
- *Vitreous painted glass* — 1275-1299 A.D.

Reims Cathedral (French 1211A.D.)

- Marc Chagall's stained glass (1974)

Prince Rupert Drops

- Drop melted glass into cold water



High internal stress

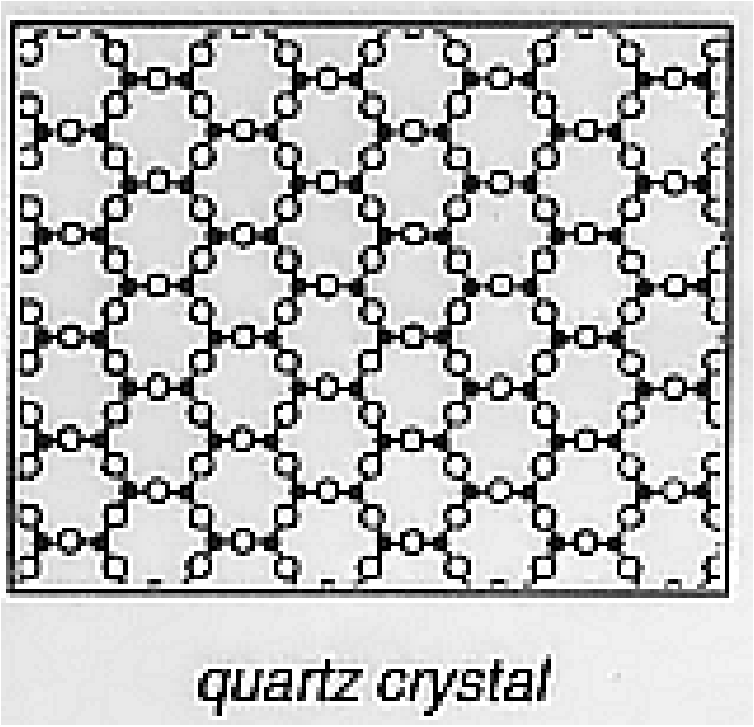
- Outside of glass cools rapidly to form tough "skin"

What is Glass?

- A non-crystalline solid
- An inorganic product of melting which has cooled to a rigid condition without crystallizing
- An amorphous solid - no long-range order
- Intermediate state between crystalline and liquid
- flows and glows upon heating

Quartz — a Crystalline Solid

Quartz or SiO_2(silica)

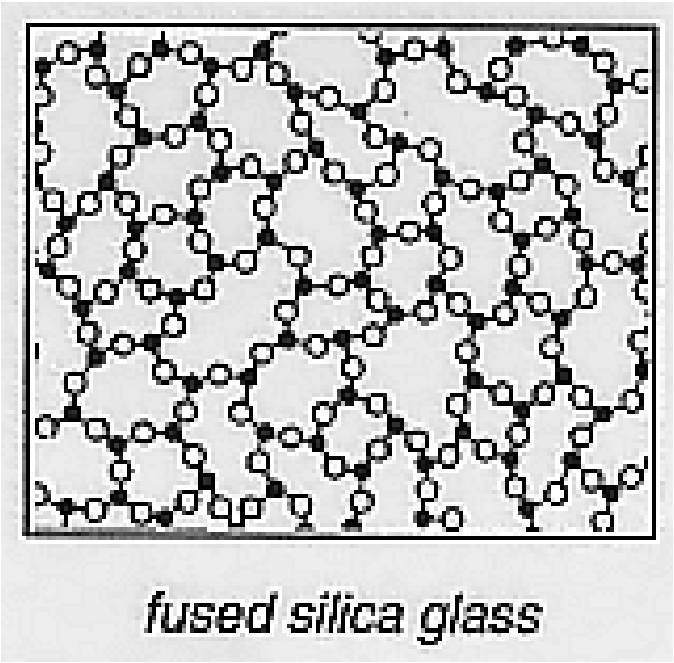


All the atoms are arranged in a regular, repeating pattern called a **crystal lattice**.

Formed by slow cooling of melted **silica**.

Glass — an Amorphous Solid

- **Silica** is the basic ingredient of glass but its crystalline order has been disrupted due to rapid cooling of the melted silica.



fused silica glass

Composition of Glasses

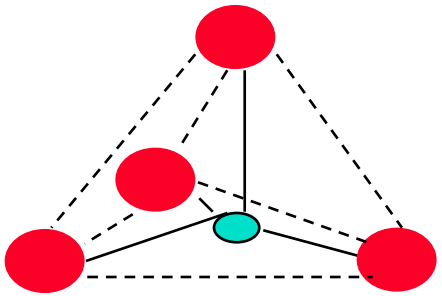
Three essential categories of oxides

- Glass Forming Oxides
  - RO_2 and R_2O_3
- Fluxing Oxides
  - RO, R_2O
- Stabilizing Oxides
  - R_2O_3

R = a metal ion

Glass Forming Oxides

- Major ingredient of a glass
- Most commonly used is SiO_2 (silica, sand)
- Also can use B_2O_3 (boric oxide)



Silica Tetrahedron

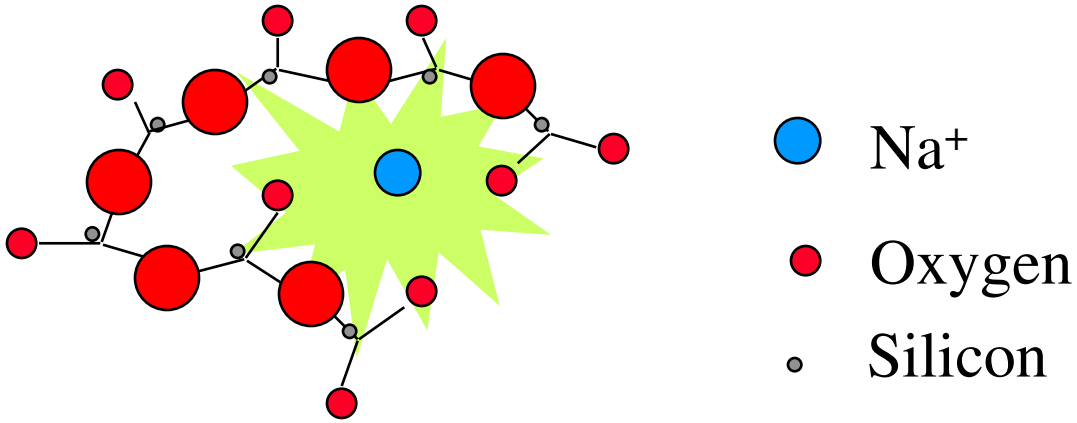
SiO_4^{-2}

Silicate ion

Oxygen ion

Silicon ion

Glass Network



- SiO_4 units linked in 3-D network by bridging the oxygen atoms
- pockets are present which can encapsulate cations in order to maintain neutral charges
- disordered array

Fluxing Oxides (**Fluxes**)

- Used to lower the melting point of silica
- Lowers the viscosity of molten glass
- Alkali oxides (R_2O)

  Na_2O (soda), K_2O (potassa), Li_2O (lithia)
- Alkaline Earth oxides (RO)

  CaO (calcia), MgO (magnesia)
- Others

  PbO, ZnO

Sources of Fluxing Oxides

- **Aluminosilicate** rocks and minerals
  - Soda feldspars

    $Na_2O \cdot Al_2O_3 \cdot 6SiO_2$
  - Potash feldspars

    $K_2O \cdot Al_2O_3 \cdot 6SiO_2$
  - Calcium feldspars

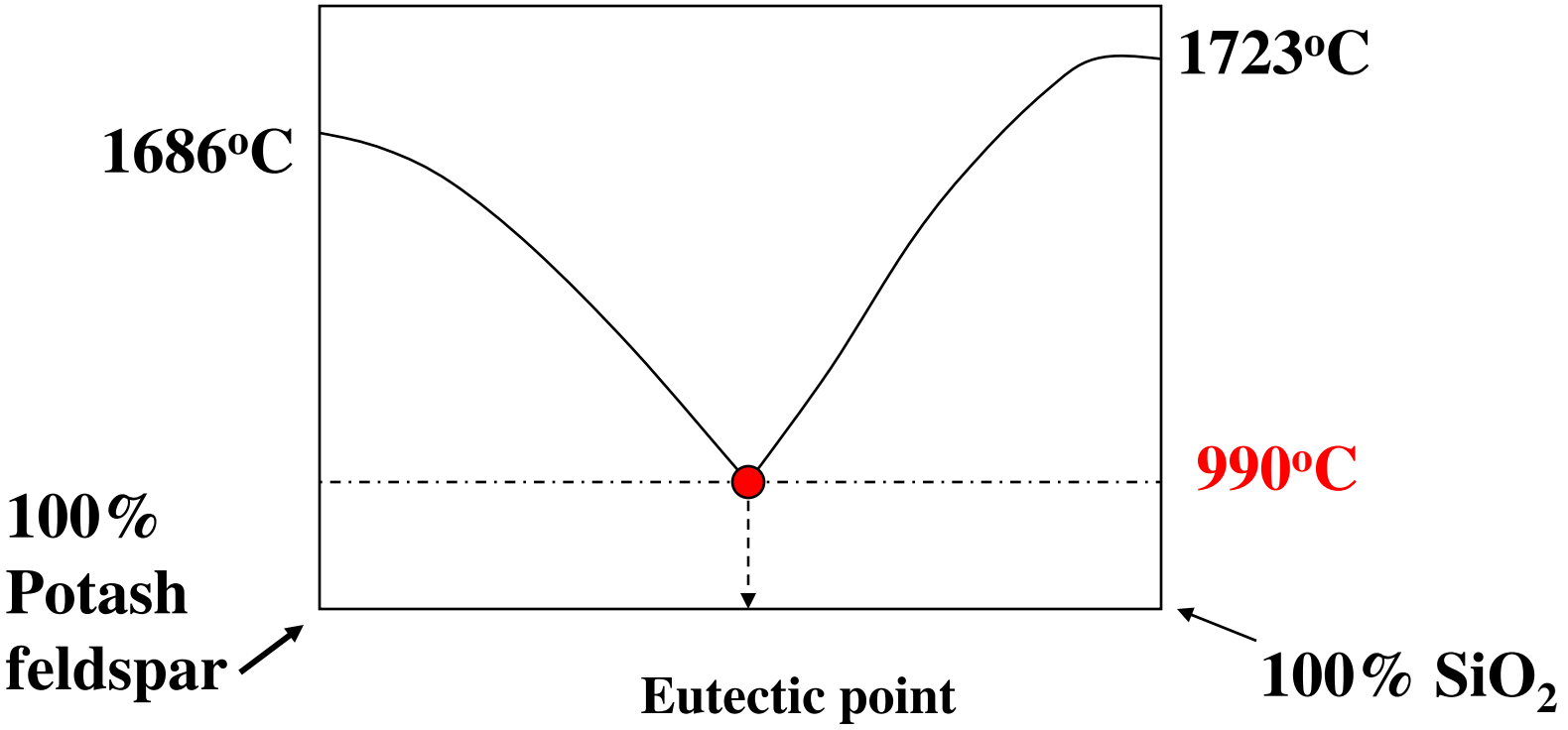
    $CaO \cdot Al_2O_3 \cdot 2SiO_2$

Nepheline Syenite

- igneous rock composed of a silicate mineral called orthoclase ($KAlSi_3O_8$)
- granite-like appearance with little or no quartz content (free SiO2)
- used to lower the melting temperature of glass and ceramic, promoting faster melting and fuel savings

Melting Point of Silica and Flux

- mp. of potash feldspar = 1686°C
- mp. of SiO_2 = 1723°C



Stabilizing or Adhesive Oxides

- Used to control viscosity, inhibit flow of molten glass, retard crystal formation
- Lower thermal expansion of glass — resistance to cracking under changing temperatures
- R_2O_3 = Al_2O_3, B_2O_3

Opacifying Oxides

- Compounds with a high refractive index added to make glass opaque

  SnO_2 = 2.04

  TiO_2 = 2.55-2.75

Milk glass

Coloring Glass

- Transition metal ionic compounds of iron, manganese, copper, cobalt, silver, gold, and uranium

http://1st-glass.1st-things.com/articles/glasscolouring.html

Glass Coloring Agents

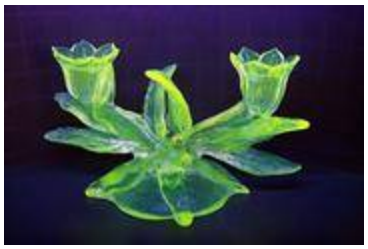
- Iron salts - ubiquitous

  Fe^{2+}

  Fe^{3+}

- Manganese

  Mn^{3+} (Mn_2O_3)



Glass Coloring Agents

- Copper

  Cu^{2+}

- Cobalt

  Co^{2+}

- Chromium

  Cr_2O_3

Glass Coloring Agents

- Nickel

  Ni^{2+}

- Gold

  Au^{2+}

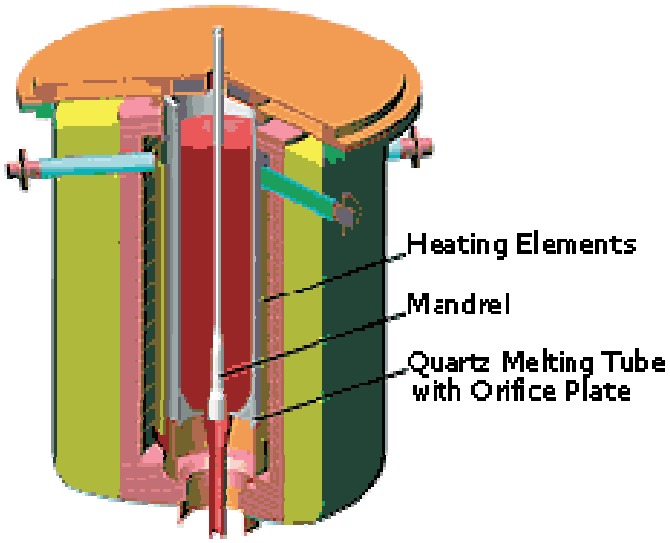
- Uranium

  U^{2+}

Glass Types

- Quartz Glass (fused silica)
- Soda-Lime Glass (window glass)
- Borosilicate Glass (scientific, Pyrex®)
- Leaded Crystal
- Specialty Glasses

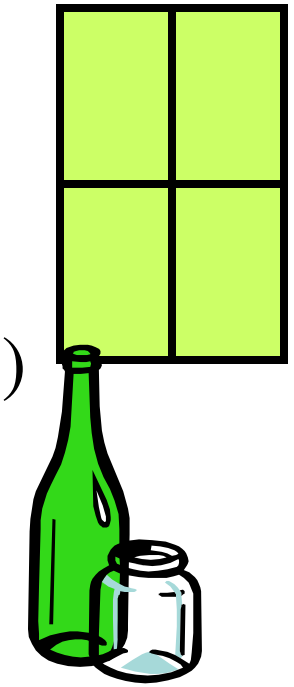
Quartz glass



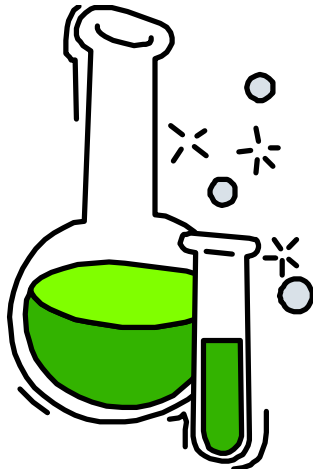
- Also called "fused silica"
- pure SiO_2
  - high mp = 1723°C, high viscosity
  - chemical and physical durability
  - transparent to visible and UV light
  - many scientific applications

Soda-Lime Glass

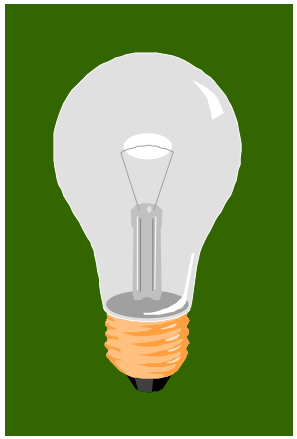
- Used to make windows, mirrors, bottles.
- SiO_2 + Na_2O + CaO
  - m.p. lowered to 1300°C
  - can be attacked by strong acids (H^+)
  - can be attacked by strong bases (OH^-)
  - high "thermal expansion" — cracks easily when heated and cooled



Borosilicate Glass



- Brand names of Pyrex®, Kimax®
- SiO_2 + Na_2O + B_2O_3
  - boron lowers thermal expansion of glass
  - lower m.p. and lower viscosity
  - durable, chemically resistant glass
  - used in scientific glassware
  - used in household cook ware



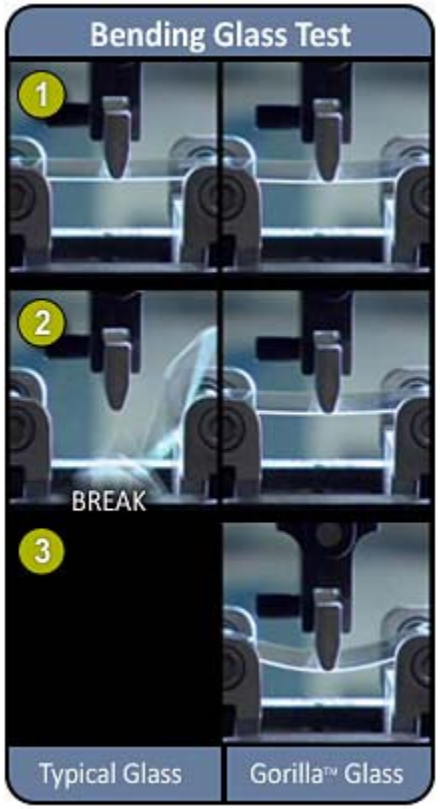
Leaded Glass

- Misnomer of "leaded crystal"
  - cut to look like crystals
- $SiO_2 + Na_2O + K_2O + PbO$
  - lowers m.p. and viscosity of glass
  - highly refractive and reflective glass
  - PbO is an historically important flux
  - poisonous in glass and unfired and fired pottery — can be leached by acids
  - used to shield from radiation (eg. TVs)

Special Glass

- Photochromic Glass
  - mid-1960's innovation out of Corning Glass
  - Contains 0.01-0.1% AgCl and CuCl
  - UV light decomposes AgCl to produce silver atoms and glass darkens (similar to photographic film)
  - In the dark the reaction is reversed by the Cu^{+} in the glass

Gorilla Glass 1962-2010!



Iridescence on Glass

- Multiple layers produced through weathering and corrosion
- Cause refraction of light and production of interference colors
- Seen in ancient and antique glass
- Carefully reproduced in art glass

Tiffanyglass

Steuben glass

Other Uses of Glassy Materials

- Glazes
  - Applied to surface of ceramics
- Enamels
  - Applied to surface of metals

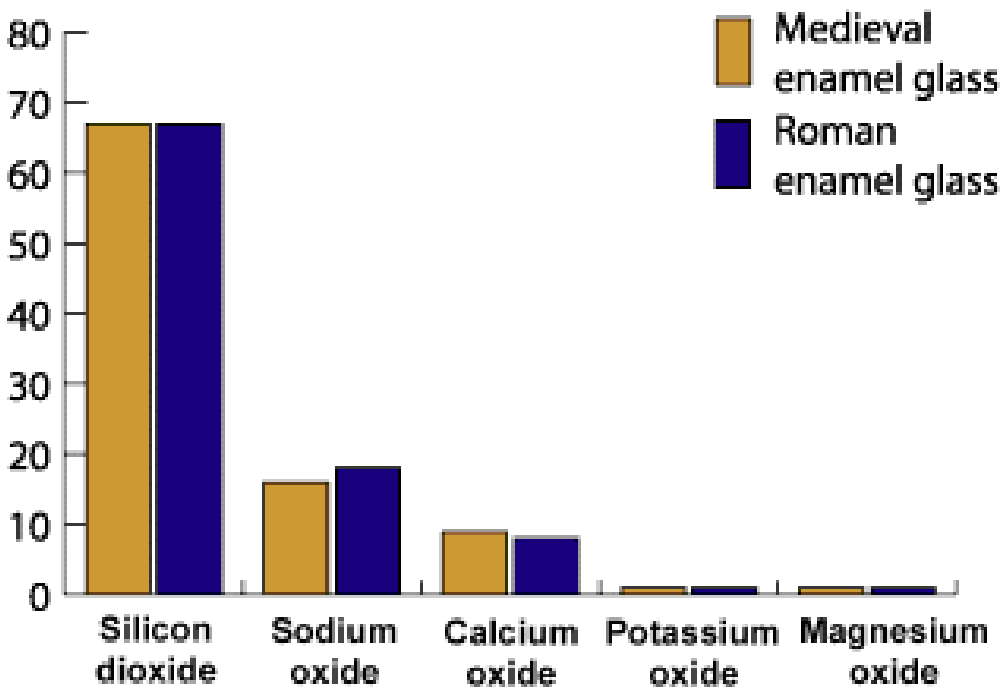
18th century bottle, Chinese

Glaze

- **Turquoise Matte**
  - Nepheline Syenite 1725
  - Strontium Carbonate 597
  - OM-4 Ball Clay 187
  - Flint 213
  - Lithium Carbonate 81
  - Copper Carbonate 81

Enamels

- British Museum study



Glaze and Enamel Composition

- Similar to glass
- Glazes usually contain more components
- Formulated to melt at lower temperatures (about 1000^{o}C)
- Glass former is silica
- Fluxing Oxides - to lower m.p.
- Stabilizing Oxides - to control fluidity

Application of Glaze and Enamel

- Glazes are usually applied as **slurries or suspensions**
- Can be applied by dipping, spraying, or painting
- Must be **thixotropic (what???)**
- Must **match thermal expansion** and contraction characteristics to those of clay body or metal surface