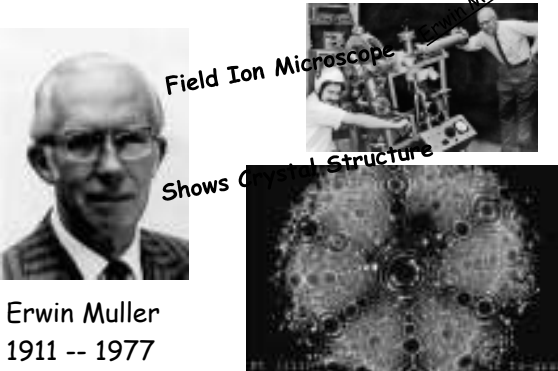


Solids

Crystal Structure Image



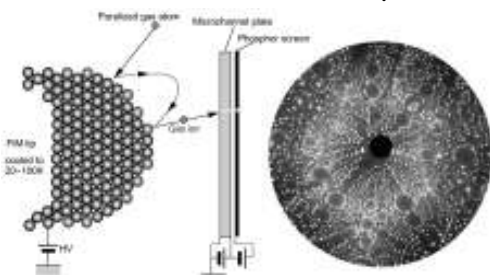
Field Ion Microscope Muller

Shows Crystal Structure

Erwin Muller
1911 -- 1977

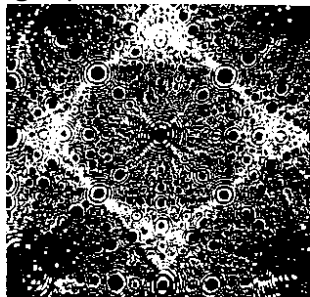
Image of Platinum Tip

Field Ion Microscope



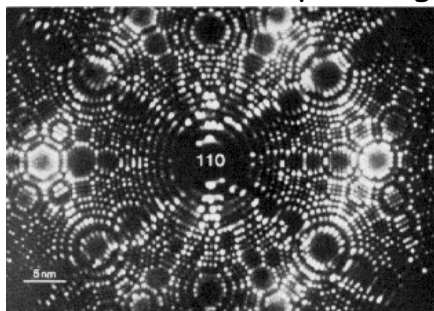
- Field-ionized atoms of the image gas form an image on the phosphor screen

Micrograph of Platinum Needle



- Image formed by ionized gas atoms on a phosphorescent screen

Field Ion Microscope Image



- Single Crystal Tungsten Tip

Standing Water Waves



Solid Classification

- Crystalline: composed of crystals, regular 3-dimensional arrays of atoms
 - Metals
 - Salts
 - Most minerals
- Amorphous: atoms and molecules distributed randomly; no orderly or repetitive arrangement
 - Rubber
 - Glass
 - Plastic

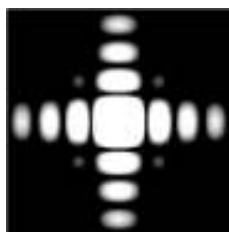
X-Ray Determination of Crystal Structure

- In 1912, used X rays to confirm that crystal is a three-dimensional orderly arrangement

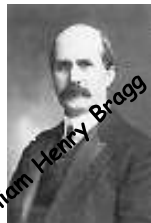
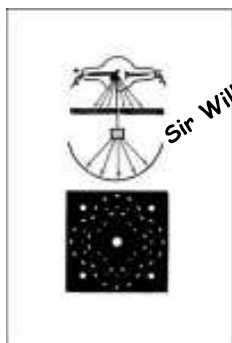


Nobel Laureate
1914

Max von Laue
1879 -- 1960



X-Ray Diffraction

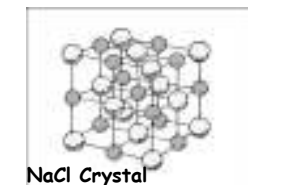


Sir William Lawrence Bragg
Sir William Henry Bragg

Father/Son Team
Nobel Prize 1915
Cambridge Physics Site

Crystals

- each atom or ion vibrates about its own position
- atoms are tied together by electrical bonding forces
 - Ionic
 - Covalent
 - Metallic
 - Van der Waals'



Density

$$\text{Density} = \frac{\text{mass}}{\text{volume}}$$

- Units:
 - kg/m³
 - kg/L
 - g/cm³
- Water:
 - 1000 kg/m³
 - 1 kg/L
 - 1 g/cm³

Material	Density (g/cm ³)
Osmium	22.6
Platinum	21.5
Gold	19.3
Mercury	13.6
Lead	11.3
Silver	10.5
Tin	7.3
Aluminum	2.7
Water @ 4°C	1.00
Ice	0.92
Ethanol	0.79

Check Yourself

- When water freezes, it expands. What does this say about the density of ice compared with the density of water?
- Ice is less dense than water (because it has more volume for the same mass), which is why ice floats on water.

Check Yourself

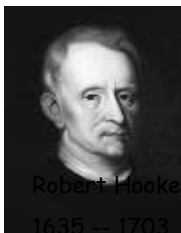
- Which weighs more, a liter of ice or a liter of water?
- Don't say the same! A liter of water weighs more. If it is frozen, then its volume will be more than a liter; chop that part off so it's the same size as the original liter, and it certainly weighs less.

Check Yourself

- Which has the greater density—100 kg of lead or 1000 kg of aluminum?
- Density is a ratio of mass and volume (or weight and volume), and this ratio is greater for any amount of lead than for any amount of aluminum

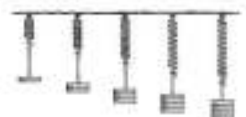
Check Yourself

- What is the density of 1000 kg of water?
- The density of any amount of water is 1000 kg/m^3 (or 1 g/cm^3)
- What is the volume of 1000 kg of water?
- The volume of 1000 kg of water is 1 m^3



Elasticity

Hooke's Law

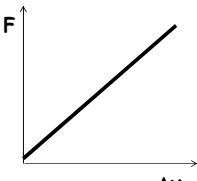


stretch of the spring is directly proportional to the applied force

$F \sim \Delta x$

$F = k \cdot \Delta x$

Can't exceed the elastic limit



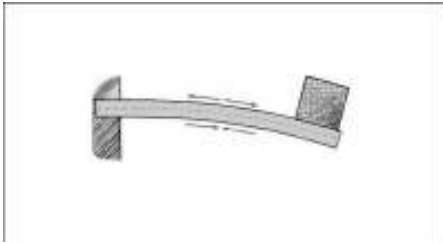
Check Yourself

- A 2-kg load is hung from the end of a spring. The spring then stretches a distance of 10 cm. If, instead, a 4-kg load is hung from the same spring, how much will the spring stretch?
- A 4-kg load has twice the weight of a 2-kg load. In accord with Hooke's law, $F \sim \Delta x$, two times the applied force will result in two times the stretch, so the spring should stretch 20 cm.

Check Yourself

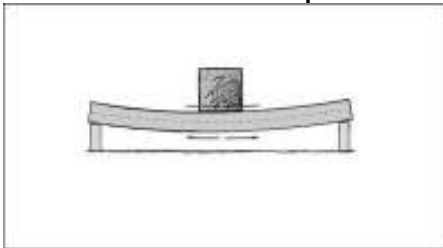
- If a force of 10 N stretches a certain spring 4 cm, how much stretch will occur for an applied force of 15 N?
- The spring will stretch 6 cm. By ratio and proportion, $10 \text{ N}/4 \text{ cm} = 15 \text{ N}/6 \text{ cm}$, which is read: 10 newtons is to 4 centimeters as 15 newtons is to 6 centimeters.

Tension and Compression



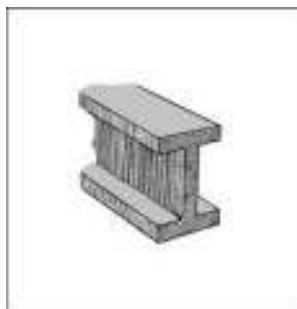
- The top part of the beam is stretched and the bottom part is compressed. What happens in the middle portion, between top and bottom?

Tension and Compression



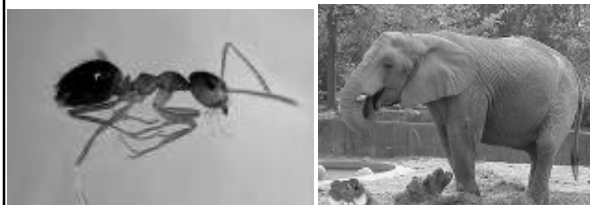
- The top part of the beam is compressed and the bottom part is stretched. Where is the neutral layer?

I-Beam



- An I-beam is like a solid bar with some of the steel scooped from its middle where it is needed least. The beam is therefore lighter for nearly the same strength.

Scaling



- Scaling is the study of how the volume and shape (size) of any object affect the relationship of its weight, strength, and surface area.

Scaling

- Ants can carry many times their own weight
- Elephants can maybe carry their own weight
- If an ant were scaled up to the size of an elephant, ...
- it would not be able to lift itself off the ground - it's legs would be too thin!

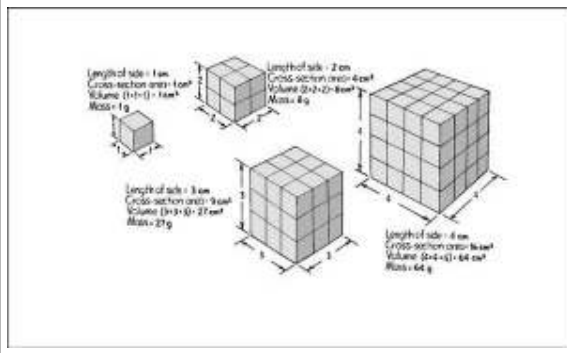
Weight versus Strength

- As the size of a thing increases, it grows heavier much faster than it grows stronger.
- Horizontally supported toothpick compared to horizontally supported tree
- Tree will sag. Toothpick won't.

Strength

- Strength comes from the area of the cross-section (which is two-dimensional and is measured in square centimeters)
- As the linear dimensions of an object change by some factor, the cross-section area changes as the square of this factor
- when the linear dimensions are doubled (factor = 2), the area grows by $2^2 = 4$

Multiplying Linear Dimension



Weight

- weight depends on volume (which is three-dimensional and is measured in cubic centimeters)
- as the linear dimensions of an object change by some factor, the volume (and hence the weight) changes as the cube of this factor
- when the linear dimensions are doubled (factor = 2), the volume grows by $2^3 = 8$.

Check Yourself

- Consider a 1-cubic centimeter cube scaled up to a cube 10 centimeters long on each edge.
- What would be the volume of the scaled-up cube?
- What would be its cross-sectional surface area?
- What would be its total surface area?

Check Your Answers

- The volume of the scaled-up cube would be $(\text{length of side})^3 = (10 \text{ cm})^3$, or 1000 cm³.
- Its cross-sectional surface area would be $(\text{length of side})^2 = (10 \text{ cm})^2$, or 100 cm².
- Its total surface area = 6 sides \times area of a side = 600 cm².


Check Yourself

- If you were somehow scaled up to twice your size while retaining your present proportions, would you be stronger or weaker? Explain your reasoning.
- Your scaled-up self would be four times as strong, because the cross-sectional area of your twice-as-thick bones and muscles increase by four. Your weight would be eight times as much as before. Having four times the strength carrying eight times the weight gives you a strength-to-weight ratio of only half its former value.

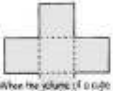
Surface Area to Volume

- As the size of an object increases, there is a greater factor of increase in volume than in surface area; as a result, the ratio of surface area to volume decreases.

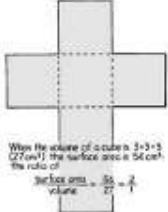
Surface Area to Volume



The surface area of a 1 cm³ volume (shown opened up) is 6 cm²! The ratio of surface area to volume = $\frac{6}{1} = 6$





When the volume of a cube is 2x2x2 (8 cm³) the surface area is 24 cm²! The ratio of surface area to volume = $\frac{24}{8} = 3$



When the volume of a cube is 3x3x3 (27 cm³) the surface area is 54 cm²! The ratio of surface area to volume = $\frac{54}{27} = 2$

Heat Radiation

The rabbit with its high surface area to weight ratio must eat often in order to make up for rapid heat loss.

- The African elephant has less surface area relative to its weight than other animals. It compensates with its large ears, which significantly increase its radiating surface area and promote cooling.

Limits Cell Growth

- Cells obtain nourishment by diffusion through the surface
- Surface area grows more slowly than the volume
- Eventually, the surface area isn't large enough to allow sufficient nutrients to pass into the cell, and the cell divides

The Harder They Fall

- Small ratio of surface area to weight
- Air resistance on an object is proportional to the surface area of the moving object
- An insect has a much smaller terminal velocity than a person

Surface Area

- Potatoes
- Coal
- Grain
- Rust on steel wool
- Crushed ice
