PHY115: Light

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Introduction

What is light?

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Light is Electromagnetic radiation

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Some other can be better explained if we consider it as particles (emision and absorsion).

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- Light is also produced during electrical discharges through ionized gases.
- In most light sources, light is emitted independently by different atoms within the source. Mixture of different wavelengths.
- In a laser, atoms are induced to emit light in a cooperative, coherent fashion. Narrow and intense monochromic beam of radiation

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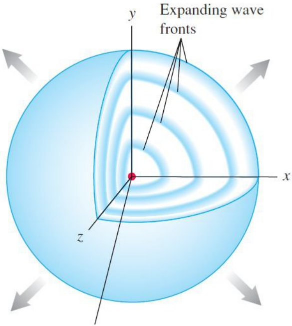
$$c = 3 \times 10^{8}\ m/s \tag{1}$$

Waves, Wave Fronts, and Rays

We define a wave front as the locus of all adjacent points at which the phase of vibration of a physical quantity associated with the wave is the same.

Waves, Wave Fronts, and Rays

Electromagnetic waves in vacuum spread out as spherical wave: waves fronts spread out uniformly in all directions from a point source.



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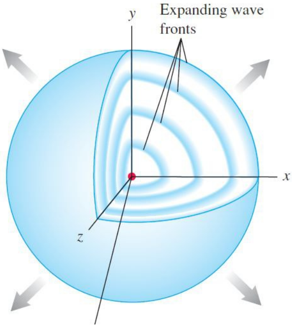

Far fron the source: Plane waves

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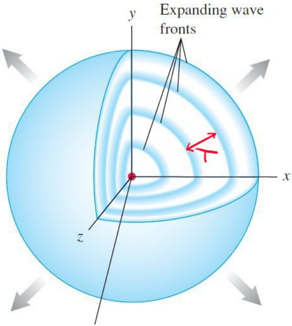

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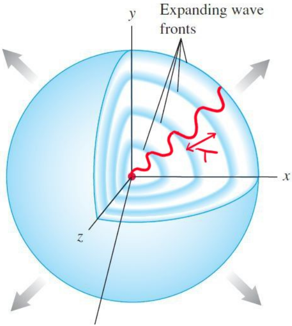

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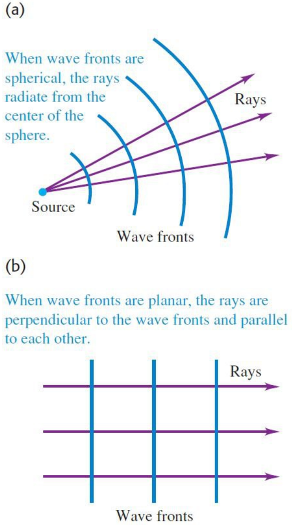
A ray is an imaginary line along the direction of travel of the wave.



Waves, Wave Fronts, and Rays

The branch of optics for which the ray description is adequate is called geometric optics; the branch dealing specifically with wave behavior is called physical optics.

Test Your Understanding of Section:

Some crystals are not isotropic: Light travels through the crystal at a higher speed in some directions than in others. In a crystal in which light travels at the same speed in the x and z-directions but at a faster speed in the y direction, what would be the shape of the wave fronts produced by a light source at the origin?

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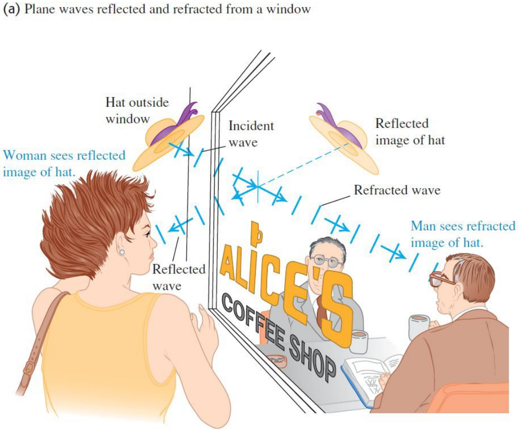
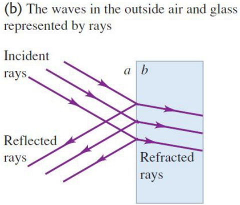
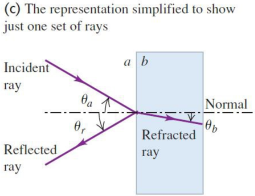
1. spherical,
2. ellipsoidal, flattened along the y-axis
3. ellipsoidal, stretched out along the y-axis.

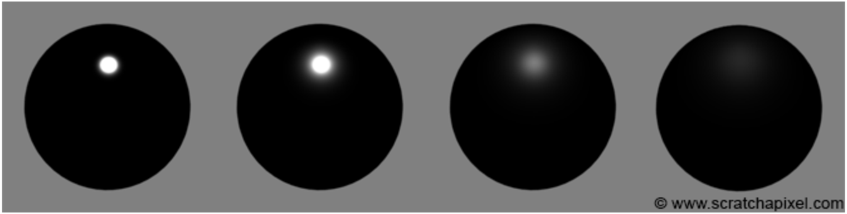
Reflection and refraction.







Two tipe of reflections: Diffuse and Specular



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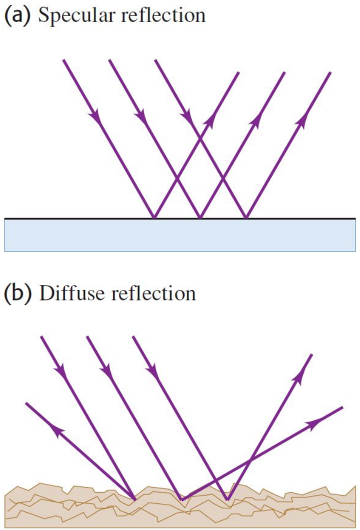

Refraction

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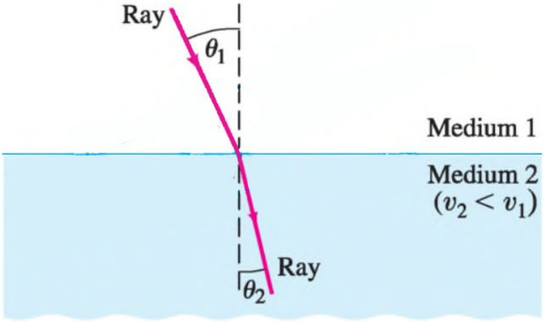
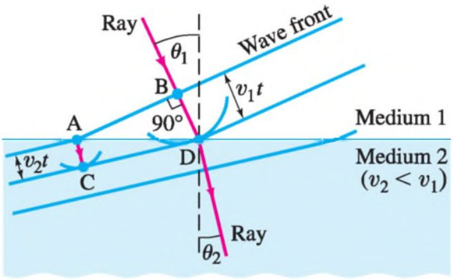
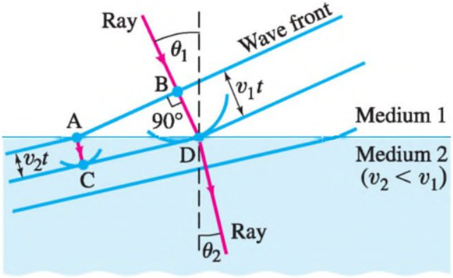


Refraction


Ray
θ_1
Wave front
B
$v_1 t$
A
90°
Medium 1
D
$v_2 t$
C
Medium 2
$(v_2 < v_1)$
Ray
θ_2

Refraction



$$sin\theta_1 = \frac{v_1 t}{AD}, \quad sin\theta_2 = \frac{v_2 t}{AD}$$

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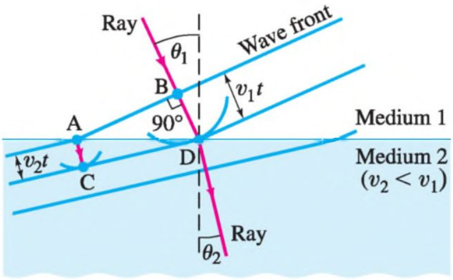

$$sin\theta_1 = \frac{v_1 t}{AD}, \quad sin\theta_2 = \frac{v_2 t}{AD}$$

$$\rightarrow \frac{sin\theta_1}{sin\theta_2} = \frac{v_1}{v_2}$$

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is the **refraction index**.

Refraction

Substance	Index of Refraction, n
Solids	
Ice (H_2O)	1.309
Fluorite (CaF_2)	1.434
Polystyrene	1.49
Rock salt (NaCl)	1.544
Quartz (SiO_2)	1.544
Zircon ($ZrO_2 \cdot SiO_2$)	1.923
Diamond (C)	2.417
Fabulite ($SrTiO_3$)	2.409
Rutile (TiO_2)	2.62
Glasses (typical values)	
Crown	1.52
Light flint	1.58
Medium flint	1.62
Dense flint	1.66
Lanthanum flint	1.80
Liquids at 20°C	
Methanol (CH_3OH)	1.329
Water (H_2O)	1.333
Ethanol (C_2H_5OH)	1.36
Carbon tetrachloride (CCl_4)	1.460

The Laws of Reflection and Refraction

1. The incident, reflected, and refracted rays and the normal to the surface all lie in the same plane (plane of incidence).
2. The angle of reflection θ_r is equal to the angle of incidence θ_a for all wavelengths and for any pair of materials.

$$\theta_r = \theta_a \; (law \;\; of \;\; reflection) \tag{3}$$

3. For monochromatic light and for a given pair of materials,

$$n_a sin\theta_a = n_b sin\theta_b \; (law \;\; of \;\; refraction, \;\; Snell) \tag{4}$$

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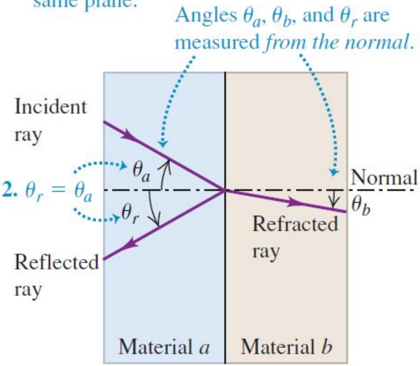


3. When a monochromatic light ray crosses the interface between two given materials a and b, the angles θ_a and θ_b are related to the indexes of refraction of a and b by

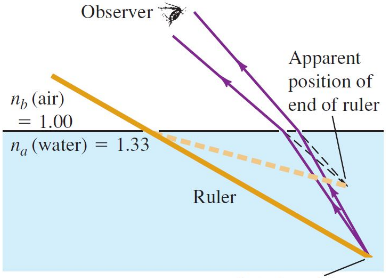
$$\frac{\sin\theta_a}{\sin\theta_b} = \frac{n_b}{n_a}$$

Refraction

Example: a straight ruler half-immersed in water

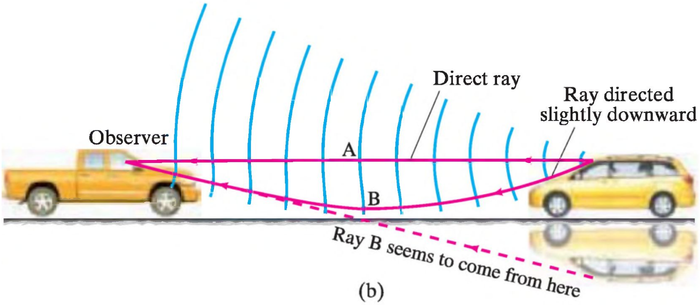
(a) A straight ruler half-immersed in water

(b) Why the ruler appears bent



Refraction

Example: Mirages



Index of Refraction and the Wave Aspects of Light

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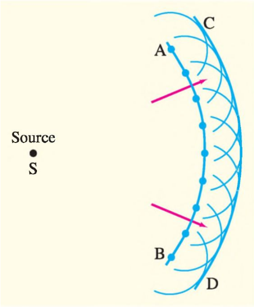
- The frequency f of the wave does not change when passing from one material to another.
- the wavelength of the wave is different in general in different materials. This is because in any material $v = \lambda f$

$$\lambda = \frac{\lambda_0}{n} \tag{5}$$

Huygens' principle

Every point on a wave front can be considered as a source o f tiny wavelets that spread out in the forward direction at the speed o f the wave itself The new wave front is the envelope o f all the wavelets— that is, the tangent to all o f them.



Diffraction

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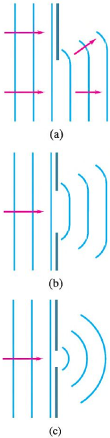
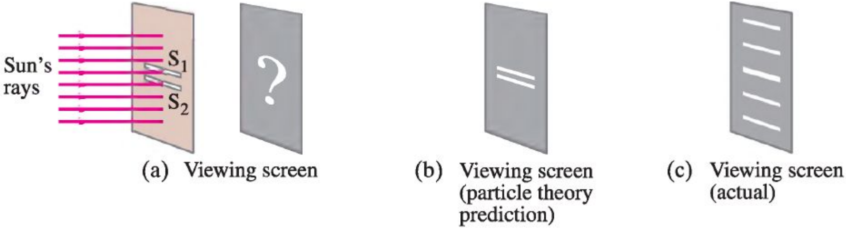


Interference: Youn's double-slit Experiment



If light consists of tiny particles, we might expect to see two bright lines on a screen placed behind the slits as in (b). But instead a series of bright lines are seen, as in (c). Young was able to explain this result as a wave-interference phenomenon.

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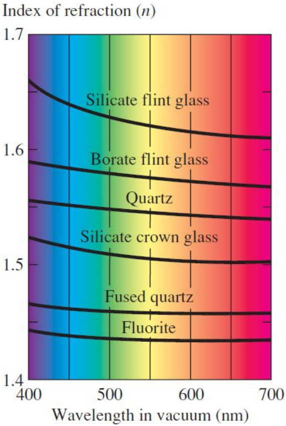
- The dependence of wave speed and index of refraction on wavelength is called **dispersion**.

How much the light ray is bent, when it is diffracted depends on n (Snell), then, the bending is different for different wavelength.



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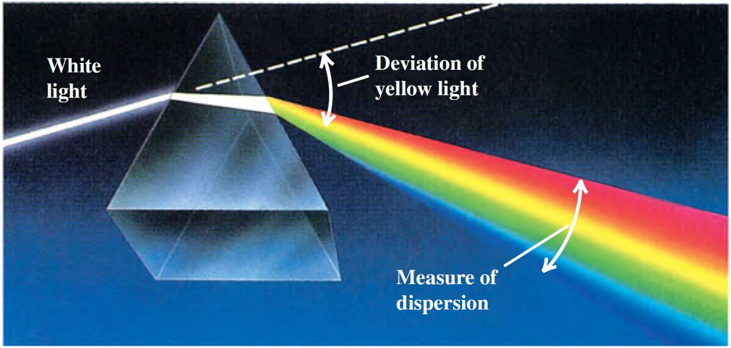

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- Huygen's principle $\rightarrow$ diffraction

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- When a light ray hits a material, it interacts with charged particles in the material
- The interaction depends on the internal structure of the material.
- The EM field accelerates the charges, and they generate electromagnetic radiation

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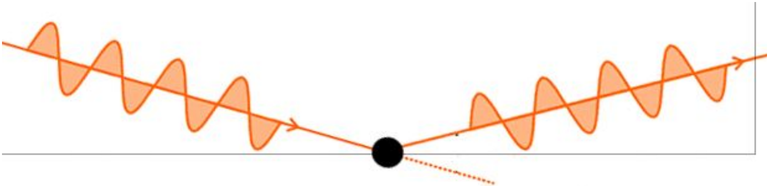

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- We can have 2 kind of scattering:
  1. Elastic: The energy is conserved, the incident angle is equal to the reflected.
  2. Inelastic: The energy is not conserved, the reflected angle changes. This happens when the light ray penetrates into the material and interacts with the atoms nuclei. The EM field makes the atoms to vibrate and is transformed into thermal energy.

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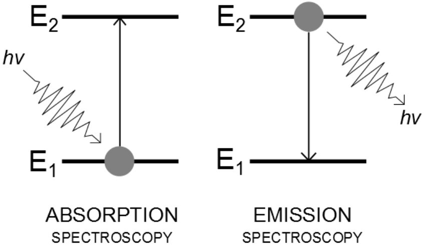

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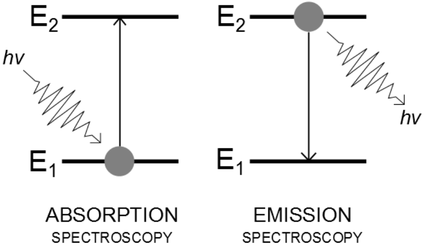

A photon can only be absorbed if its energy is equal to the gap.

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We only can observe Reflected or Transmitted frequencies. If some frequencies are absorbed, the Reflected or Transmitted light does not have all the frequencies, so it is not white anymore. $\rightarrow$ Color

Fresnel Reflectance

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The Fresnel coefficients describe the reflection and transmission of light. It gives us an idea of the ratio between the light reflected and the light transmitted.

- transparent materials have low Fresnel coefficients
- opaques materials have high Fresnel coefficients
- it depends on the angle of incidence
- it also depends on the Index Of Reflection (IOR)

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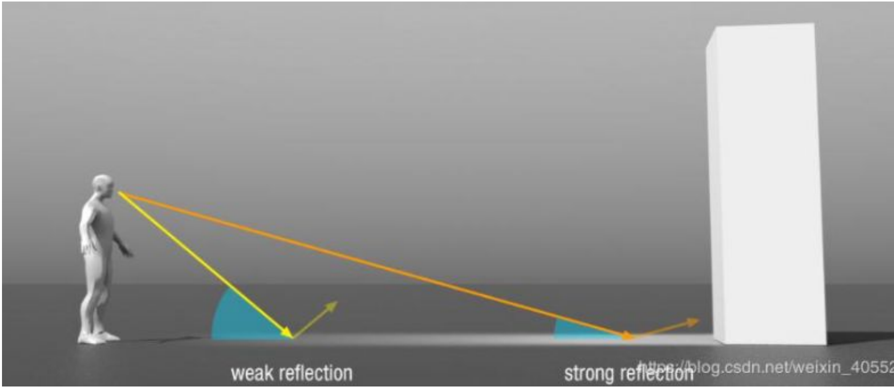

So, what happens in different materials?

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METALS

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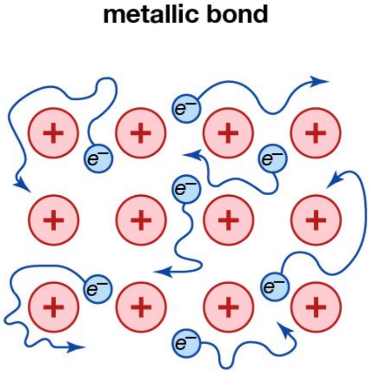
METALS

Metallic bonding can be thought as a cloud of positive charge ions immersed in a cloud of valence electrons.

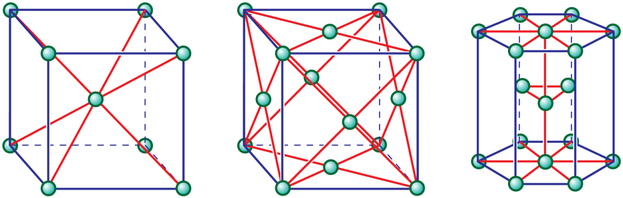


METALS

METALS

The positive ions, form a net:

Common metallic crystal structures



body-centred cubic (bcc)   face-centred cubic (fcc)   hexagonal close-packed (hcp)

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- $\rightarrow$ High electric conductivity, heat conductivity.
- When the metal is exposed to an electric field, the electrons are redistributed around the material so that the electric field inside is 0.

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When a photon interacts with an atom in the metal, 3 things can happen:

1. Elastic Scattering: High ratio, specular reflection
2. Inelastic Scattering: Low ratio, light intensity is highly dumped inside the metal. So it does not interact with the net.
3. Absorption: Low ratio, electrons energy gap is too big for visible light.

1. Specular reflection for all the visible light frequencies $\rightarrow$ not colored
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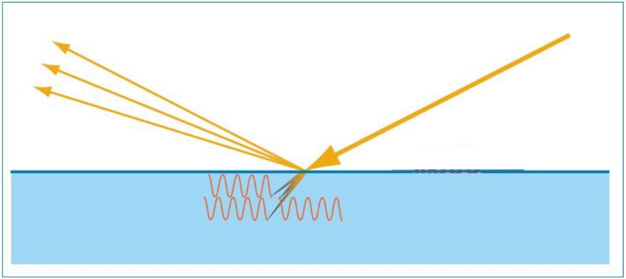

Structure of non-metallic solids

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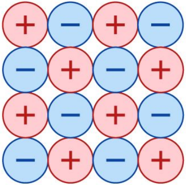
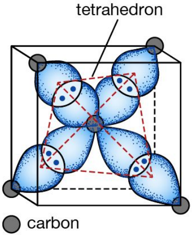
ionic bond



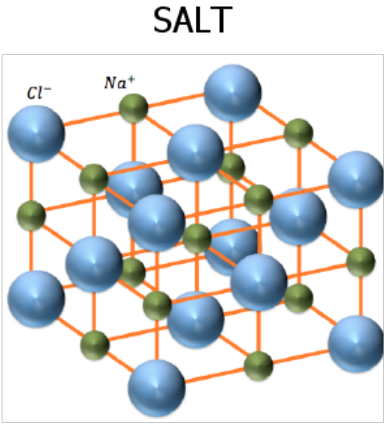
An idealized ionic (or electrovalent) bonding of oppositely charged ions.

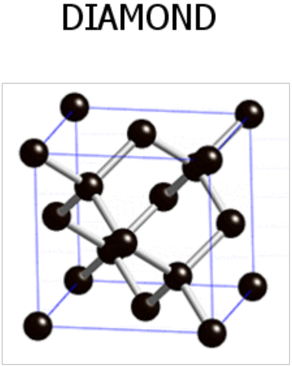
covalent bond



Covalent bonds involve electron sharing, such as between these carbon atoms when they form a diamond.

Structure of non-metallic solids





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- When the material is exposed to an electric field, it interacts with electrons and the ions in the net, they emit EM radiation. The resultant EM radiation is a superposition of both, it is a wave with a slower velocity (refraction law).

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