CONTENT BEYOND SYLLABUS

NEUTRINO DECAY

A **neutrino** is a fermion (an elementary particle with half-integer spin) that interacts only via the weak subatomic force and gravity. The mass of the neutrino is much smaller than that of the other known elementary particles. The neutrino is so named because it is electrically neutral and because its rest mass is so small (-*ino*) that it was originally thought to be zero. The weak force has a very short range, gravity is extremely weak on the subatomic scale, and neutrinos, as leptons, do not participate in the strong interaction. Thus, neutrinos typically pass through normal matter unimpeded and undetected.

Weak interactions create neutrinos in one of three leptonic flavors: electron neutrinos (νe), muon neutrinos (νμ), or tau neutrinos (ντ), in association with the corresponding charged lepton. Although neutrinos were long believed to be massless, it is now known that there are three discrete neutrino masses with different tiny values. A neutrino created is in an associated specific quantum superposition of all three mass states. Although only differences of squares of the three mass values are known as of 2016, cosmological observations imply that the sum of the three masses must be less than one millionth that of the electron.

For each neutrino, there also exists a corresponding antiparticle, called an *antineutrino*, which also has half-integer spin and no electric charge. They are distinguished from the neutrinos by having opposite signs of lepton number and chirality. To conserve total lepton number, in nuclear beta decay, electron neutrinos appear together with only positrons (anti-electrons) or electron-antineutrinos, and electron antineutrinos with electrons or electron neutrinos.The two types of beta decay are known as *beta minus* and *beta plus*. In beta minus (β^-) decay a neutron is converted to a proton and the process creates an electron and an electron antineutrino, while in beta plus (β^+) decay a proton is converted to a neutron and the process creates a positron and an electron neutrino. β^+ decay is also known as positron emission.

Beta decay conserves a quantum number known as the lepton number, or the number of electrons and their associated neutrinos (other leptons are the muon and tau particles). These particles have lepton number +1, while their antiparticles have lepton number −1. Since a proton or neutron has lepton number zero, β^+ decay (a positron, or antielectron) must be accompanied with an electron neutrino, while β^- decay (an electron) must be accompanied by an electron antineutrino.An example of electron emission (β^- decay) is the decay of carbon-14 into nitrogen-14 with a half-life of about 5,730 years:

146C→ 147N+ e−+ νe

In this form of decay, the original element becomes a new chemical element in a process known as nuclear transmutation. This new element has an unchanged mass number *A*, but an atomic number *Z* that is increased by one. As in all nuclear decays, the decaying element (in this case 14 6C) is known as the *parent nuclide* while the resulting element (in this case 147N) is known as the *daughter nuclide*.

ENERGY BANDS IN SOLIDS

On the basis of the band structure, crystals can be classified into metals, insulators, and semi-conductors.

Metal

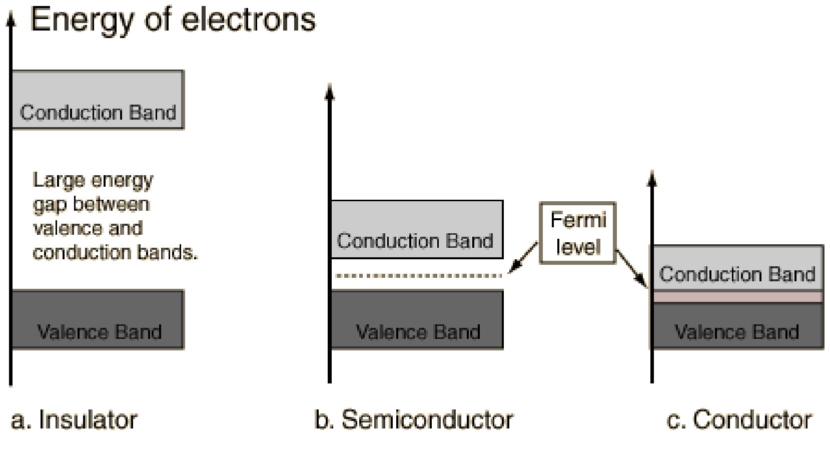
A crystalline solid is called a metal if the uppermost energy band is partly filled or the uppermost filled band and the next unoccupied band overlap in energy. Here, the electrons in the uppermost band find neighbouring vacant states to move in, and thus behave as free particles. In the presence of an applied electric field, these electrons gain energy from the field and produce an electric current, so that a metal is a good conductor of electricity. The partly filled band is called the conduction band . The electrons in the conduction band are known as free electrons or conduction electrons.

Insulator

In some crystalline solids, the forbidden energy gap between the uppermost filled band, called the valence band, and the lowermost empty band, called the conduction band, is very large. In such solids, at ordinary temperatures only a few electrons can acquire enough thermal energy to move from the valence band into the conduction band. Such solids are known as insulators. Since only a few free electrons are available in the conduction band, an insulator is a bad conductor of electricity. Diamond having a forbidden gap of 6 eV is a good example of an insulator.

Semiconductor

A material for which the width of the forbidden energy gap between the valence and the conduction band is relatively small (~ 1 eV) is referred to as a semiconductor. Germanium and silicon having forbidden gaps of 0.78 and 1.2 eV, respectively, at 0 K are typical semiconductors. As the forbidden gap is not very wide, some of the valence electrons acquire enough thermal energy to go into the conduction band. These electrons then become free and can move about under the action of an applied electric field. The absence of an electron in the valence band is referred to as a hole. The holes also serve as carriers of electricity. The electrical conductivity of a semiconductor is less than that of a metal but greater than that of an insulator.



BIOMATERIALS

Biomaterials science is that branch of biomedical engineering that is concerned with the materials aspects of medical devices. Any material, metal, ceramic, plastic or organic brought into contact with the fluids, cells and tissues of the living body come within the domain of biomaterials science. Developments in biomaterials are the result of an interesting combination of technologists and scientists.

Any biomaterial should have the property of biocompatibility such that the biomaterial is capable of existing together with the biosystem in a harmonious and homogeneous manner so that it would not react with the biofluids. Its physical, chemical and mechanical properties should not be degraded with respect to ageing. They have high compatibility, high strength and corrosion resistance.

The major classifications of the biomaterials are

(a) Metals and Alloys

(b) Polymers

(c) Ceramics

BCS THEORY

The microscopic theory of superconductivity developed by J.Bardeen, L. N. Cooper and J.R. Schrieffer in 1957, successfully explained the effects like zero resistivity, Meissner effect etc. This theory is known as BCS theory.

Important features of BCS theory

(i) Electrons form pairs (called Cooper pairs) which propogate throughout the Lattice

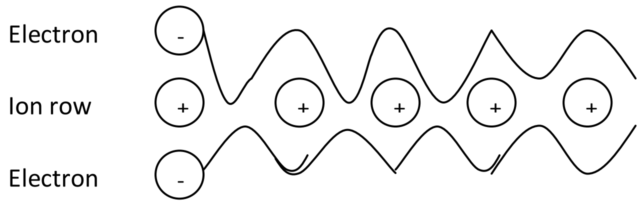
(ii) The propagation of cooper pairs is without resistance because the electrons move in resonance with phonons.

Therefore, the interaction described by the BCS theory is known as the **electron – phonon interaction.**

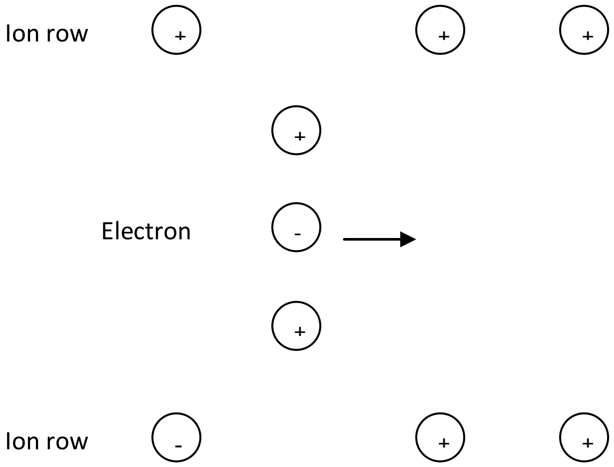
To explain the formation of cooper pair, consider the model in fig (a), in which two electrons propagate along a single lattice row. Each electron experiences an attraction towards its nearest positive ion.

When the electrons get very close to each other in the region between ions, they repel each other due to their mutual coulomb force.

In an equilibrium condition, a balance between attraction and repulsion is established and the two electrons combine to form cooper pair. The collection of such cooper pair (bosons) in a bulk sample condenses to form the superconducting state.



(a)



(b)

Figure- Movement of electrons (a) in a one – dimensional lattice (b) between rows of a two dimensional lattice.

In order to explain the zero resistivity exhibited by the superconductors, consider one of the electrons of the cooper pair propagating through the lattice as shown fig (b). The coulomb attraction between the electron and ions deforms the lattice which is propagated along with the electron.

This propagating wave is associated with phonon transmission and the electron – phonon resonance allows the electron along with its pair elsewhere in the lattice to move without resistance.

PHOTO ELECTRIC EFFECT

Whenever light or electromagnetic radiations such as X-rays, ultraviolet rays falls on a metal surface, it emits electrons.

The process of emission of electrons from a metal plate when illuminated by the light of suitable wavelength is called the photoelectric effect.

The electrons emitted are known as the photoelectrons as they are emitted by the action of light. The resulting current is known as photo –electric current.

Experimental verification of photoelectric effect:-

Photo electric effect can be easily studied with the help of the apparatus shown in Fig.

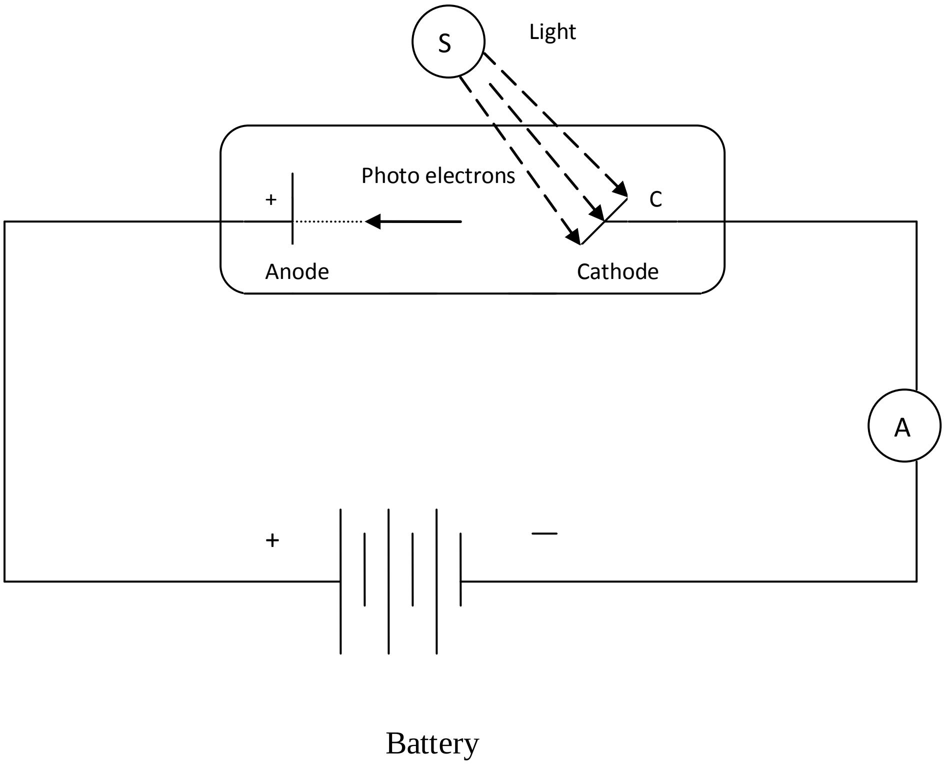


Figure – Photo electric effect

It consists of a photo sensitive plate C (called cathode) and another metal plate A (called anode) enclosed in an evacuated quartz tube.

The following observations is made

1. In the absence of light, there is no flow of current in the circuit and the ammeter A reads zero

2. When the light of suitable wavelength from a source falls on the surface of Cathode C, electrons are emitted from the cathode. These photo electrons are immediately attracted by the positive anode (collector plate) thereby constituting current in the circuit as indicated by ammeter.

CRYSTAL DEFECTS

The term defect is used to describe any deviation from the perfect periodic array of atoms in the crystal. Crystalline defects can be classified on the basis of their geometry under four main divisions, namely:

1. Point defects
   - (a) Vacancies
   - (b) Interstitials
   - (c) Impurities
   - (d) Electronic defects
2. Line defects
   - (a) Edge dislocation
   - (b) Screw dislocation
3. Surface defects
   - (a) Grain boundaries
   - (b) Tilt boundaries
   - (c) Twin boundaries
   - (d) Stacking faults
   - (e) Ferromagnetic domain walls

4. Volume defects

(a) Cracks

(b) Voids or Air bubbles

<u>Point defects:-</u>

Point defects are also called as zero dimensional defects. They are imperfect point – like regions in the crystal.

Vacancies: A vacancy or vacant site implies an unoccupied atom position within the crystal lattice. Ion vacancies are called Schottky defects.

Interstitials: An interstitial defect arises when an atom occupies a definite position in the lattice that is not normally occupied in the perfect crystal. An ion displacement in the ionic crystals is called a Frenkel defect.

Impurities: Impurities give rise to compositional defects.

Electronic defects: They are the result of errors in charge distribution in solids.

<u>Line defects:-</u>

Line defects are called dislocations. A dislocation may be defined as a disturbed region between two substantially perfect parts of a crystal.

Edge dislocation: It is created in the crystal by introducing an extra half plane.

Screw dislocation: It results from a displacement of the atoms in one part of a crystal relative to the rest of the crystal.

<u>Surface defects:-</u>

Surface defects which are two dimensional refer to regions of distortions that lie about a surface having a thickness of a few atomic diameters. These are also called plane defects.

Grain boundaries: The grain boundaries are those surface imperfections which separate crystals of different orientations in a polycrystalline aggregate.

Tilt boundaries: It may be regarded as an array of edge dislocations.

Twin boundaries: Surface imperfections which separate two orientations that are mirror images of one another are called twin boundaries.

Stacking faults: A stacking fault is a surface imperfection that results from the stacking of one atomic plane out of sequence on another, while the lattice on either side of the fault is perfect.

Ferromagnetic

Domain walls: When two ferromagnetic regions differ from one another only in the direction of magnetization, the boundary between them is an imperfection and is called a ferromagnetic domain wall.

Volume defects:-

Cracks: It arises when there is only small electrostatic dissimilarity between the stacking sequence of closed packed planes in metals.

Voids or Air bubbles: It arises when clusters of atoms are missing in the crystal.

EFFECTIVE MASS OF ELECTRON IN SEMICONDUCTORS AND INSULATORS (CONCEPT OF HOLE)

1. The effective mass plays an important role in the conduction process in semiconductors and insulators since they have full or almost filled valence bands.
2. We can find that the effective mass, m^* is negative near the zone edges of almost filled valence bands. Physically speaking the electrons in these regions are accelerated in a direction opposite to the direction of the applied force. This is called the negative mass behavior of electrons.
3. The electrons with negative mass can be considered as a new entity having the same positive mass of that electron and the same positive charge as the numerical value of the electron's charge. The new entity is given the name, 'hole'.

4. The advantage of the concept of positive holes is that the momentum and current of a nearly filled band with n empty states can be attributed to the presence of an equivalent number of n holes with the same positive mass and positive charge of that of electron.
5. The holes are not real particles like electrons or positrons, but it is only a way of looking at the negative mass behavior electrons near the zone edge.
6. We look upon the motion of the effective negative mass electrons as the motion of the positive holes or positive vacant sites in a nearly full band and allow the electrons in the band to carry the current. The positive hole conduction and effective negative electron mass conduction are equivalent situations.
7. Calculations made on the hole picture is advantageously retained. Several phenomena like Hall effect, Thomson effect, etc., find ready explanation on the basis of the hole concept.
8. Thus the hole is a vacant state in the valence band of a semiconductor or insulator. In the applied electric field, it behaves as a particle having positive electron mass and the same positive charge as the numerical value of the electron's charge. The hole concept is used to explain the motion of the effective negative mass electrons in a nearly filled band.

JOSEPHSON EFFECT AND ITS APPLICATIONS

Josephson effects are due to tunneling of cooper pairs. According to Josephson effect, the tunneling of cooper pairs could take place between two superconductors separated by an insulator even in the absence of applied voltage between the superconductors. Let us discuss d.c. Josephson effect and a.c. Josephson effect.

D.C. Josephson effect: A d.c. current flows across the junction of two superconductors separated by a thin insulating layer in the absence of any electric or magnetic field.

A.C. Josephson effect: A d.c. voltage applied across the junction of two superconductors separated by a thin insulating layer causes r.f. current oscillations across the junction with frequency, $\omega = (q / \hbar) V$. Further if a rf voltage is applied along with the d.c. voltage, there is a flow of d.c. current across the junction.

Let V_o be the applied voltage and V_c be the minimum value of dc voltage required to produce a.c. Josephson effect.

1. If $V_o = 0$, there is a constant flow of d.c. current equal to i_c through the junction. This current is called superconducting current. This effect is the d.c. Josephson effect.
2. If $V_o < V_c$, we have a constant flow of d.c. current equal to i_c only.

3. When $V_o > V_c$, the junction has a finite resistance and the current oscillates with a frequency, $\omega = (q / \hbar) V_o$ where q = 2e = charge of cooper pair. This represents the a.c. Josephson effect.
4. If the applied voltage is the sum of d.c. voltage and a.c. voltage such that a.c. voltage is lesser than d.c. voltage, then a d.c. current flows through the junction.

Applications

1. It is used to produce microwave waves with a frequency, $\upsilon = 2eV / h$ where V = d.c voltage applied across the Josephson junction. The weak connections between superconductors through which the Josephson effects are produced, form Josephson junction.
2. Using a.c. Josephson effect the value of standard volt can be defined by the National Bureau of Standards with very high accuracy.

   Thus 1 volt = (483593420 MHz) (h / 2e)

3. The a.c. Josephson effect is used to measure very low temperatures based on the variation of frequency of the emitted radiation with temperature.
4. A Josephson junction is capable of switching signals from one circuit to another with a switching time of 1 ps. Thus the Josephson junction circuits are capable of storing information. Since a Josephson junction is a superconducting device whose power consumption is extremely small and size and weight are very small, the Josephson junction computer has been fabricated with a volume of $1.25 \times 10^{-4}\ m^3$ and a cycle time of 2 ns which is 10 times faster than the high speed semiconductor based computer.

SECOND HARMONIC GENERATION (SHG)

NON-LINEAR OPTICS:

Non-linear phenomena are, higher harmonic generation, optical mixing, parametric amplification optical phase conjugation, solution etc.,

HIGHER HARMONIC GENERATION:

In a linear medium, polarization P is proportional to the electric filed E that induces it.

$$P = \chi \varepsilon_0 E$$

Where χ is the electric susceptibility.

In nonlinear medium, for higher fields, i.e., higher intensities of light.

$$P = \varepsilon_0 (\chi_1 E + \chi_2 E^2 + \chi_3 E^3 + ...)$$

Where χ_1 is the linear susceptibility and χ_2, χ_3 …….. are higher order nonlinear susceptibilities. With increase of filed higher order terms come into play. Let us assume that the field is strong enough to give rise to χ_2, then

$$P = \varepsilon_0 \ (\chi_1 E + \chi_2 E^2)$$

The electric field passing through the medium can be represented by E = E_0Cos ω*t*, Hence,

$$P = \varepsilon_0 (\chi_1 E_0 \cos wt + \chi_2 E_0^2 \cos^2 wt)$$

$$= \varepsilon_0 \chi_1 E_0 \cos wt + \varepsilon_0 \chi_2 E_0^2 \frac{(1 + \cos 2wt)}{2}$$

$$= \frac{1}{2} \varepsilon_0 \chi_2 E_0^2 + \varepsilon_0 \chi_1 E_0 \cos wt + \frac{1}{2} \varepsilon_0 \chi_2 E_0^2 \cos 2wt$$

The nonlinear polarization indicates that it contains the second harmonic of ω (third term) as well as an average (d.c.) term (first term) called optical rectification. It can be shown that only in the crystals lacking inversion symmetry; second harmonic generation (SHG) is possible. SHG crystals are Quartz, Potassium dihydrogen phosphate (KDP), Ammonium dihydrogen phosphate (ADP), Barium titanate ($BaTiO_3$) and Lithium Iodate ($LiIO_3$).

The fundamental radiation from a laser is pass through SHG crystal, due to SHG, it converts into double the frequency i.e., half the wavelength takes place. For example 1.064μm radiation from Nd: YAG laser gets converted to 0.532μm on passing through crystals like KDP, ADP etc.

If the incident radiation from the laser is intense enough such that the polarization needs to be represented by three terms, then

$$P = \varepsilon_0 (\chi_1 E + \chi_2 E^2 + \chi_3 E^3)$$

$$= \varepsilon_0 (\chi_1 E_0 \cos wt + \chi_2 E_0^2 \cos^2 wt + \chi_3 E_0^3 \cos^3 wt)$$

$$= \frac{1}{2} \varepsilon_0 \chi_2 E_0^2 + (\varepsilon_0 \chi_1 E_0 + \frac{3}{4} \varepsilon_0 \chi_3 E_0^3) \cos wt + \frac{1}{2} \varepsilon_0 \chi_2 E_0^2 \cos 2wt + \frac{1}{4} \varepsilon_0 \chi_3 E_0^3 \cos 3wt$$

The last term in the above equation represents third harmonic generation at frequency 3ω. Likewise one can account for higher harmonic generation.

OPTICAL MIXING:

The generation of new frequencies with help of nonlinear phenomena is called optical mixing. Suppose two coherent waves of unequal frequencies, ω_1 and ω_2 are traversing the material, then

$$E = E_1 \cos \omega_1 t + E_2 \cos \omega_2 t$$

Hence

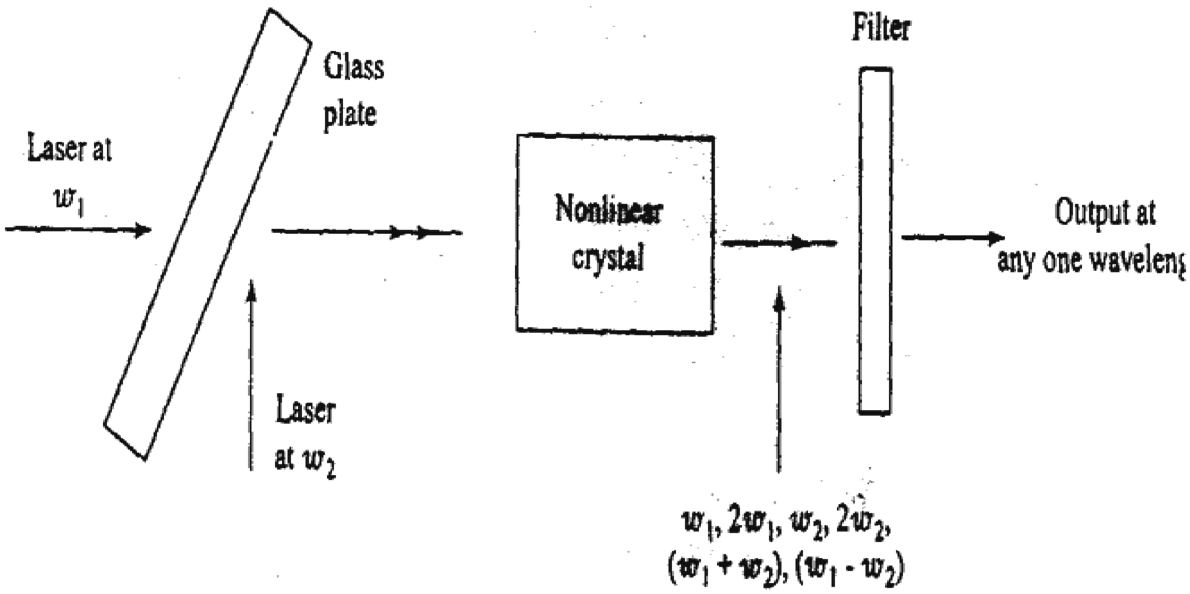
$$P = \varepsilon_0 \chi_1 (E_1 \cos\omega_1 t + E_2 \cos\omega_2 t) + \varepsilon_0 \chi_2 (E_1^2 \cos^2 \omega_1 t + E_2^2 \cos^2 \omega_2 t) + 2\varepsilon_0 \chi_2 E_1 E_2 \cos\omega_1 t \cos\omega$$

The second term gives rise to $2\omega_2$. The last term can be expressed as

$$2\varepsilon_0 \chi_2 E_1 E_2 \cos \omega_1 t = \varepsilon_0 \chi_2 E_1 E_2 [\cos (\omega_1 + \omega_2) t + \cos (\omega_1 - \omega_2) t]$$

Thus waves of frequencies ω_1, $2\omega_1$, ω_2, $2\omega_2$, $(\omega_1+\omega_2)$ and $(\omega_1-\omega_2)$ are generated. Using proper optical arrangement it is possible to get sufficiently intense output at any one of these frequencies.

The generation of $(\omega_1+ \omega_2)$ is called frequency-up conversion and $(\omega_1-\omega_2)$ is called frequency-down conversion Crystals like KDP, ADP are used for up conversion while $LiNbO_3$, quartz are used for down conversion.



Arrangement for Generating A New Frequency By Optical Mixing