CONTENT BEYOND SYLLABUS

THE PHOTOELECTRIC EFFECT

The photoelectric effect is studied in part because it can be an introduction to wave-particle duality and quantum mechanics.

When a surface is exposed to sufficiently energetic electromagnetic energy, light will be absorbed and electrons will be emitted. The threshold frequency is different for different materials. It is visible light for alkali metals, near-ultraviolet light for other metals, and extreme-ultraviolet radiation for nonmetals. The photoelectric effect occurs with photons having energies from a few electron volts to over 1 MeV. At the high photon energies comparable to the electron rest energy of 511 keV, Compton scattering may occur pair production may take place at energies over 1.022 MeV.

Einstein proposed that light consisted of quanta, which we call photons. He suggested that the energy in each quantum of light was equal to the frequency multiplied by a constant (Planck's constant) and that a photon with a frequency over a certain threshold would have sufficient energy to eject a single electron, producing the photoelectric effect. It turns out that light does not need to be quantized in order to explain the photoelectric effect, but some textbooks persist in saying that the photoelectric effect demonstrates the particle nature of light.

Einstein's Equations for the Photoelectric Effect:

Einstein's interpretation of the photoelectric effect results in equations which are valid for visible and ultraviolet light:

Energy of photon = energy needed to remove an electron + kinetic energy of the emitted electron

$$h\nu = W + E$$

where,

h is Planck's constant

ν is the frequency of the incident photon

W is the work function, which is the minimum energy required to remove an electron from the surface of a given metal: $h\nu_0$

E is the maximum kinetic energy of ejected electrons: $1/2\ mv^2$

v_0 is the threshold frequency for the photoelectric effect

m is the rest mass of the ejected electron

v is the speed of the ejected electron

No electron will be emitted if the incident photon's energy is less than the work function. Applying Einstein's special theory of relativity, the relation between energy (E) and momentum (p) of a particle is,
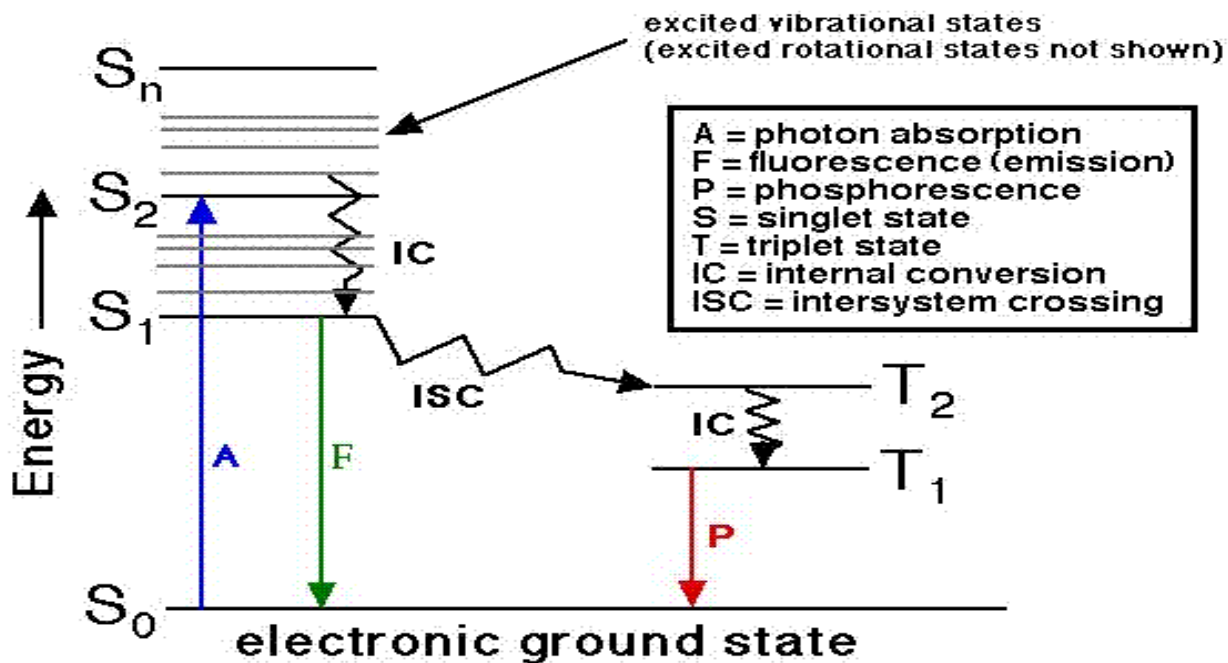
$$E = [(pc)^2 + (mc^2)^2]^{(1/2)}$$

Where m is the rest mass of the particle and c is the velocity of light in a vacuum.

The rate at which photoelectrons are ejected is directly proportional to the intensity of the incident light, for a given frequency of incident radiation and metal.

- The time between the incidence and emission of a photoelectron is very small, less than 10^{-9} second.

- For a given metal, there is a minimum frequency of incident radiation below which the photoelectric effect will not occur so no photoelectrons can be emitted (threshold frequency).

- Above the threshold frequency, the maximum kinetic energy of the emitted photoelectron depends on the frequency of the incident radiation but is independent of its intensity.

- If the incident light is linearly polarized then the directional distribution of emitted electrons will peak in the direction of polarization (the direction of the electric field).

PHOTOLUMINESCENCE

The phenomenon of temporary light absorption and subsequent light emission is called Photoluminescence

excited vibrational states
(excited rotational states not shown)

A = photon absorption
F = fluorescence (emission)
P = phosphorescence
S = singlet state
T = triplet state
IC = internal conversion
ISC = intersystem crossing

Kasha's Rule: Photoluminescence always from S_1 (fluorescence) or T_1 (phosphorescence

- Absorption (10^{-15} s)

- Internal conversion (10^{-12} s)

- Intersystem crossing (heavy-atom enhanced)

- Quenching by external quenchers (diffusion-controlled)

- Fluorescence (10^{-9} s)

- Phosphorescence/Inorganic luminescence (10^{-5} - 10^1 s)

IMPORTANT CHARACTERISTICS OF PHOTOLUMINESCENCE

Each Photoluminescence substance has its own excitation and emission spectra. The intensity of the Photoluminescence is proportional to its absorption, which in turn is proportional to the excitation light. The Photoluminescence emission of a substance is always at a higher wavelength than the light used to excite the substance (Stokes-shift phenomenon).The Photoluminescence of a substance is sensitive to many factors and will change or even disappear under different conditions.

ADVANTAGE OF USING PHOTOLUMINESCENCE AS RESEARCH TOOL

- It is very sensitive

- It allows to measure very small amount of substance in a given sample

- It allows to measure very small changes

- It allows to track conformational changes

- It is very safe

- It is very fast

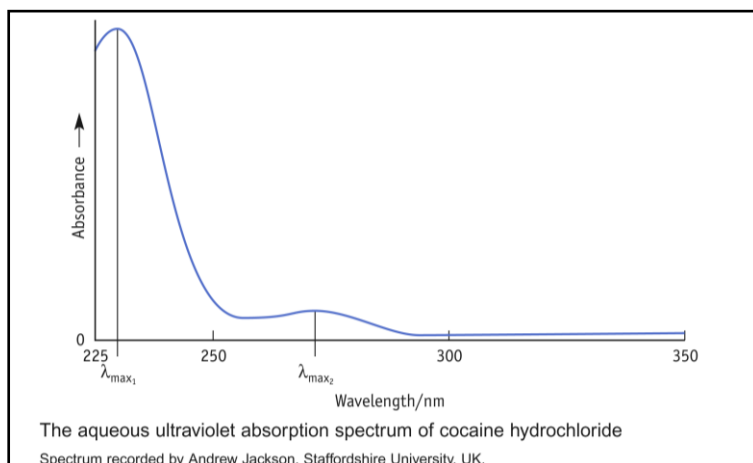- It is cost-effective

- It is widely used in every research

WHAT CAN BE MEASURED OF A PHOTOLUMINESCENCE SUBSTANCE

- Photoluminescence intensity

- Excitation spectra

- Emission spectra

- Photoluminescence lifetime

- Anisotropy & Polarization

- Time-based Photoluminescence intensity

- Time-based Photoluminescence lifetime

UV-VISIBLE SPECTROSCOPY

Ultraviolet radiation stimulates molecular vibrations and electronic transitions. Absorption spectroscopy from 160 nm to 780 nm. Measurement absorption or transmittance Identification of inorganic and organic species.

MODEL GRAPH:

The aqueous ultraviolet absorption spectrum of cocaine hydrochloride
Spectrum recorded by Andrew Jackson, Staffordshire University, UK.

Electronic transitions:

Electronic transitions occur when the molecule absorbs energy

- p, s, and n electrons

- d and f electrons

  Charge transfer

Limitations of the Beer-Lambert law

The linearity of the Beer-Lambert law is limited by chemical and instrumental factors. Causes of nonlinearity include:

Deviations in absorptive coefficients at high concentrations (>0.01M) due to electrostatic interactions between molecules in close proximity. Interaction with solvent: hydrogen bonding. Scattering of light due to particulates in the sample. Fluorescence or phosphorescence- a positive deviation in % T and negative deviation for A. changes in refractive index at high analyze concentration shifts in chemical equilibrium as a function of concentration. Non-monochromatic radiation, deviations can be minimized by using a relatively flat part of the absorption spectrum such as the maximum of an absorption band, stray light.
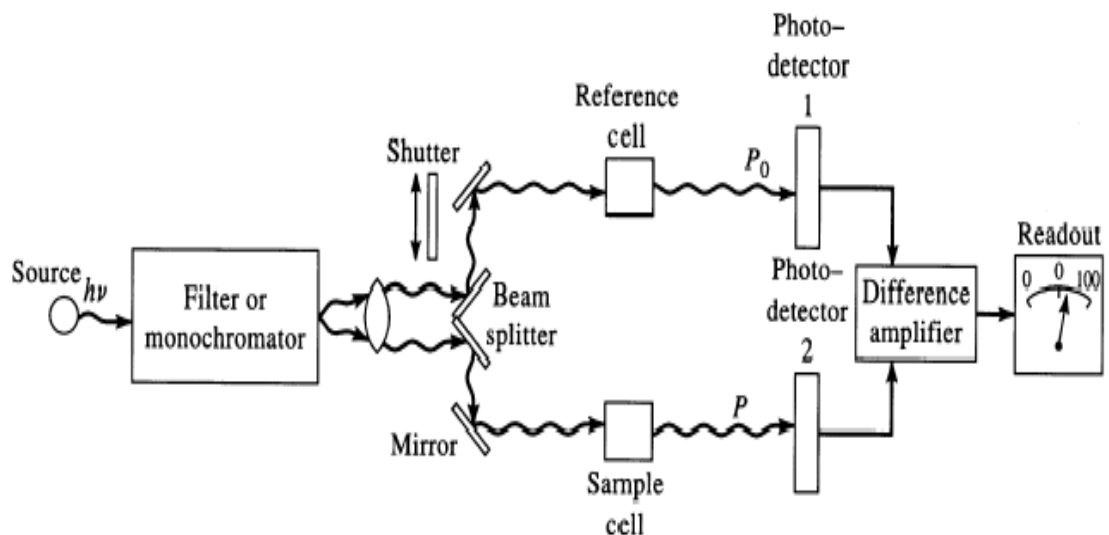
NON-DESTRUCTIVE TESTING

Non-Destructive Testing (NDT) is a wide group of analysis techniques used in science and industry to evaluate the properties of a material, component or system without causing damage. The terms Nondestructive examination (NDE), Nondestructive inspection (NDI), and Nondestructive evaluation (NDE) are also commonly used to describe this technology.

Non-destructive Testing is one part of the function of Quality Control and is Complementary to other long established methods. By definition non-destructive testing is the testing of materials, for surface or internal flaws or metallurgical condition, without interfering in any way with the integrity of the material or its suitability for service.

Radiography:

This technique is suitable for the detection of internal defects in ferrous and nonferrous metals and other materials. X-rays, generated electrically, and Gamma rays emitted from radio-active isotopes, are penetrating radiation which is differentially absorbed by the material through which it passes; the greater the thickness, the greater the absorption. Furthermore, the denser the material the greater the absorption.

X and Gamma rays also have the property, like light, of partially converting silver halide crystals in a photographic film to metallic silver, in proportion to the intensity of the radiation reaching the film, and therefore forming a latent image. This can be developed and fixed in a similar way to normal photographic film. Material with internal voids is tested by placing the subject between the source of radiation and the film. The voids show as darkened areas, where more radiation has reached the film, on a clear background. The principles are the same for both X and Gamma radiography.

In X-radiography the penetrating power is determined by the number of volts applied to the X-Ray tube - in steel approximately 1000 volts per inch thickness is necessary. In Gamma radiography the isotope governs the penetrating power and is unalterable in each isotope. Thus Iridium 192 is used for 1/2" to 1" steel and Caesium 134 is used for 3/4" to 21/2" steel. In X-radiography the intensity, and therefore the exposure time, is governed by the amperage of the cathode in the tube. Exposure time is usually expressed in terms of milliampere minutes. With Gamma rays the intensity of the radiation is set at the time of supply of the isotope. The intensity of radiation from isotopes is measured in Becquerel's and reduces over a period of time.
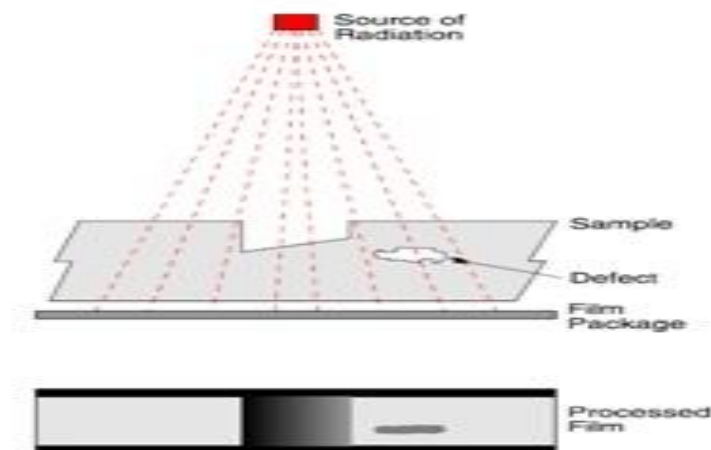
The time taken to decay to half the amount of curies is the half life and is characteristic of each isotope. For example, the half life of Iridium 192 is 74 days, and Caesium 134 is 2.1 years. The exposure factor is a product of the number of curies and time, usually expressed in curie hours. The time of exposure must be increased as the isotope decays - when the exposure period becomes uneconomical the isotope must be renewed. As the isotope is continuously emitting radiation it must be housed in a container of depleted uranium or similar dense shielding material, whilst not exposed to protect the environment and personnel.

Magnetic Particle Inspection:

This method is suitable for the detection of surface and near surface discontinuities in magnetic material, mainly ferrite steel and iron. An Illustration of the Principle of Magnetic Particle Inspection
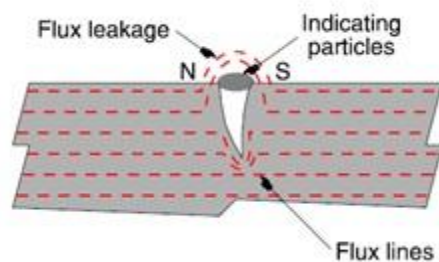
The principle is to generate magnetic flux in the article to be examined, with the flux lines running along the surface at right angles to the suspected defect. Where the flux lines approach a discontinuity they will stay out in to the air at the mouth of the crack. The crack edge becomes magnetic attractive poles North and South. These have the power to attract finely divided particles of magnetic material such as iron fillings. Usually these particles are of an oxide of iron in the size range 20 to 30 microns, and are suspended in a liquid which provides mobility for the particles on the surface of the test piece, assisting their migration to the crack edges. However, in some instances they can be applied in a dry powder form.

The particles can be red or black oxide, or they can be coated with a substance, which fluoresces brilliantly under ultra-violet illumination (black light). The object is to present as great a contrast as possible between the crack indication and the material background. The technique not only detects those defects which are not normally visible to the unaided eye, but also renders easily visible those defects which would otherwise require close scrutiny of the surface. There are many methods of generating magnetic flux in the test piece, the simplest one being the application of a permanent magnet to the surface, but this method cannot be controlled accurately because of indifferent surface contact and deterioration in magnetic strength. Modern equipments generate the magnetic field electrically either directly or indirectly. Eddy Current and Electro-Magnetic Methods

The main applications of the eddy current technique are for the detection of surface or subsurface flaws, conductivity measurement and coating thickness measurement. The technique is sensitive to the material conductivity, permeability and dimensions of a product. Eddy currents can be produced in any electrically conducting material that is subjected to an alternating magnetic field (typically 10Hz to 10MHz). The alternating magnetic field is normally generated by passing an alternating current through a coil. The coil can have many shapes and can between 10 and 500 turns of wire.
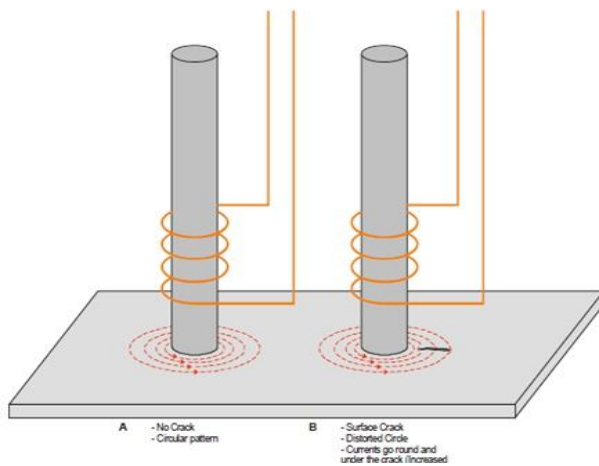
The magnitude of the eddy currents generated in the product is dependent on conductivity, permeability and the set up geometry. Any change in the material or geometry can be detected by the excitation coil as a change in the coil impedance The most simple coil comprises a ferrite rod with several turns of wire wound at one end and which is positioned close to the surface of the product to be tested. When a crack, for example, occurs in the product surface the eddy currents must travel farther around the crack and this is detected by the impedance change

WORK FUNCTION

Definition:

Work function is defined as the minimum amount of energy required by an electron to escape from a metal surface.

Concept of Work Function in Classical Physics:

The concept of work function is not to hard to understand. The concept can be explained by either classical physics or quantum mechanism. As per classical physics, when an electron tries to escape from metal surface, it leaves a positive image behind in the metal surface. Due attraction of this positive image negative electron turns back to metal surface hence cannot leave the metal crystal permanently. But to overcome this attraction force an electron requires sufficient energy supplied from outside normally from external light source.

The minimum energy requires escaping an electron form a metal surface is called work function.

Concept of Work Function in Quantum Physics:

Work function can also be explained and defined by quantum physics. For that, we first have to know some basic features.

1. Sir Albert Einstein said that light is in the form of a beam of a huge number of discrete energy packets called photons. The energy contains in each photon is $h\lambda$. Where, h is Planck Constant and λ is the frequency of light.

2. Now when the light strikes on a metal surface electron on the surface of the metal get energy from the light and get emitted from the surface. This is classically termed as photoemission.

3. As the energy of photon $E_{ph} = h\,\lambda$. The energy of each photon depends upon the frequency of light. As the frequency is everything upon which energy of photon rather light depends, it is found that there will be no photoemission from a metal surface below a certain frequency of light. For minimum photoemission frequency of incident light is required.

4. If the frequency of light is higher than that above mention minimum rate for photoemission, then the extra energy of photon will be converted to Kinetic energy of the emitted electron. Hence, how fast the electron will be emitted from the surface of the metal depends upon the frequency of incident light. Not on the intensity (Brightness of the light).

5. But when an intensity of incident light increases without changing its frequency. Obviously, number of photons strike on the metal surface hence more emitted electrons will be produced, but Kinetic energy of each electron will be unchanged as the frequency of incident light is fixed.

6. Hence after a certain minimum frequency the electrons start emitted from a metal surface. Above this frequency, the Kinetic energy of the emitted electron is directly proportional to incident light frequency. But below this minimum frequency, there will be no Kinetic energy in the electrons.

Graphical Representation of Work Function:

Now, If we graphically represent the above points we will get the graph below,

Here, the vertical axis represents the energy of an electron and horizontal axis represents the frequency.

Energy × 10⁻

Threshold
Frequency f_0

Frequency × 10¹⁴

Work
function,
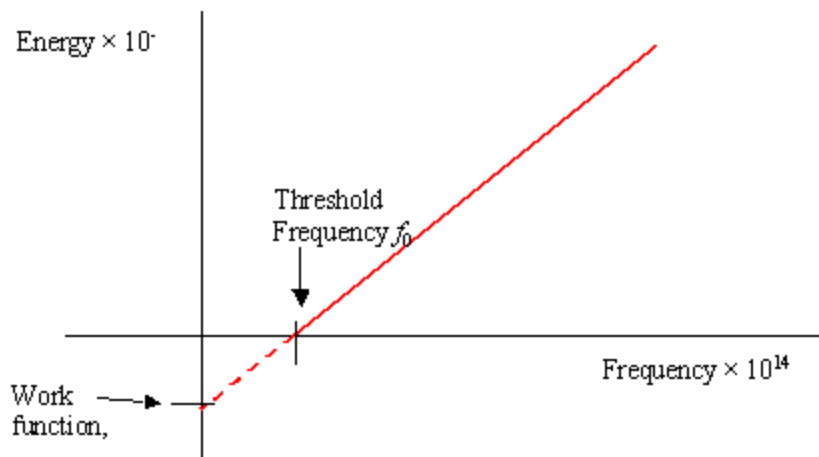
After frequency f_o Hz, the Kinetic energy of electrons start increasing proportionally with frequency. Below, frequency fo or below energy hf_o [h is Planck Constant] there will be no kinetic energy i.e. no emission of an electron. This amount of energy i.e. hf_o is known and defined as work function λ.

PIEZOELECTRICITY AND APPLICATIONS

Introduction:

Piezoelectricity is the ability of some materials such as crystals and certain ceramics, to generate an electric potential in response to applied mechanical stress or heat. If the piezo crystals are not short-circuited, the applied charge induces a voltage across the material.

The word Piezo is derived from the Greek "Piezein", which means to squeeze or press. The Piezo material exhibits both "Direct piezo electric effect" as well as 'Converse Piezo electric effect". Direct piezo electric effect is the production of electricity when the crystals are mechanically stressed and the converse piezo electric effect is the stress or strain in the crystals when an electric potential is applied. The most common crystals used is lead zirconate titanate crystals.

The Piezo effect finds many applications such as the production and detection of sound, generation of high voltages, electronic frequency generation, microbalances, and ultra fine focusing of optical assemblies. It is also the basis of a number of scientific instrumental techniques with atomic resolution, the scanning probe microscopes and everyday uses such as acting as the ignition source for cigarette lighters and push-start propane barbecues.

Working:

In a piezoelectric crystal, the positive and negative electrical charges are separated, but symmetrically distributed. This makes the crystal electrically neutral. Each of these sides forms an electric dipole and dipoles near each other tend to be aligned in regions called "Weiss domains". The domains are usually randomly oriented, but can be aligned during poling, a process by which a strong electric field is applied across the material, usually at elevated temperatures. When a mechanical stress is applied, this symmetry is disturbed, and the charge asymmetry generates a voltage across the material. In Converse piezoelectric effect, application of an electrical field creates mechanical deformation in the crystal.

The most common application of Piezo crystals to generate a potential is the electric cigarette lighter. Pressing the button of the lighter causes a spring-loaded hammer to hit a piezoelectric crystal, producing a sufficiently high voltage that electric current flows across a small spark gap, thus heating and igniting the gas. Some substances like quartz can generate potential differences of thousands of volts through direct Piezo electric effect.

Piezo Buzzer   **Piezo element**
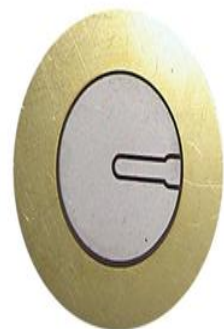
The best-known application of Piezo crystals are

1. Direct piezoelectricity of some substances like quartz, as mentioned above, can generate potential differences of thousands of volts

2. As sensing elements

Detection of pressure variations in the form of sound is the most common sensor application, e.g. piezoelectric microphones. Sound waves bend the piezoelectric material, creating a changing voltage

3. Ultrasound imaging

Piezoelectric sensors are used with high frequency sound in ultrasonic transducers for medical imaging .For many sensing techniques, the sensor can act as both a sensor and an actuator. Ultrasonic transducers, for example, can inject ultrasound waves into the body, receive the returned wave, and convert it to an electrical signal (a voltage).

4. Sonar sensors

Piezoelectric elements are also used in the detection and generation of sonar waves. Applications include power monitoring in high power applications such as medical treatment, sonochemistry and industrial processing etc.

5. As chemical and biological sensors

Piezoelectric microbalances are used as very sensitive chemical and biological sensors. Piezo are also used as strain gauges.

6. In Music instruments

Piezoelectric transducers are used in electronic drum pads to detect the impact of the drummer's sticks.

7. Automotive application

Automotive engine management systems use a piezoelectric transducer to detect detonation by sampling the vibrations of the engine block. Ultrasonic piezo sensors are used in the detection of acoustic emissions in acoustic emission testing.

8. Piezoresistive silicon devices

The Piezoresistive effect of semiconductors has been used for sensor devices employing all kinds of semiconductor materials such as germanium, polycrystalline silicon, amorphous silicon, and single crystal silicon. Since silicon is today the material of choice for integrated digital and analog circuits the use of Piezoresistive silicon devices has been of great interest. It enables the easy integration of stress sensors with Bipolar and CMOS circuits.

9. Piezoresistors are resistors made from a Piezoresistive material and are usually used for measurement of mechanical stress. They are the simplest form of Piezoresistive device.

The Piezoresistive effect

It is the changing electrical resistance of a material due to applied mechanical stress. The Piezoresistive effect differs from the piezoelectric effect. In contrast to the piezoelectric effect, the Piezoresistive effect only causes a change in resistance; it does not produce an electric potential.

Piezo sensor   **Piezo microphone**

ENERGY BANDS IN SOLIDS

In an isolated atom, the electrons are tightly bound and have discrete sharp energy levels. When two identical atoms are brought together the energy levels of each atom which are initially the same are split into two, one higher and one lower than the corresponding levels of the separated atoms. The splitting only because appreciable when the wave functions of the electrons on different atoms begin to overlap considerably; at a given distance it is therefore greatest for the outermost electrons and least for the inner electrons. If more atoms are brought together more levels are formed and for a solid of N atoms, each of the energy level of an atom splits into N levels of energy. The levels are so close together that

they form an almost continuous band. The width of this band depends on the degree of overlap of electrons on adjacent atoms and is again largest for the outermost atomic electrons. The bands are appeared only when the distance between two atoms is very small. That is the bands are formed in solid only. For example, when the distance between two sodium atoms is about 5Å the splitting of energy levels is maximum and bands are appeared. But when the distance between two sodium atoms is about 20 Å the splitting of energy levels is minimum and there is no band formation and hence there is no solid formation. The electrons can take only the energy values whish are in the band. The gap between two allowed bands is called forbidden energy gap (or) band gap since the electron cannot take the values of energy which are in the forbidden energy gap. Normally we are interested in the valance (outermost energy) band, formed by valence electrons since that are responsible for electrical thermal and optical properties of solids. Above the valence band there is conduction band which has no electrons are 0 K.