SYLLABUS

2018 -2020 BATCH

KARPAGAM ACADEMY OF HIGHER EDUCATION
(Deemed to be University)
(Established Under Section 3 of UGC Act 1956)
Coimbatore – 641 021.
(For the candidates admitted from 2018 onwards)
DEPARTMENT OF PHYSICS

SUBJECT: CONDENSED MATTER PHYSICS

SEMESTER : I

SUBJECT CODE: 18PHP101

Scope: Study of properties of materials is very important at all times, to choose the correct material for the correct use. Especially with the development of nanotechnology, it is important to give an idea about the preparation methods and characterization of different materials.

Objectives: This paper is intended to give the students an idea about importance of crystals and their properties. An introduction to nanotechnology is also given in this paper.

UNIT – I

Inter planar spacing: Inter planar spacing for SC, FCC, BCC lattices - diamond cubic structure - NaCl structure - The reciprocal lattice and their properties - Bragg condition in terms of reciprocal lattice.

Crystal defects: Classification of defects - Points defect - The Schottky defect - The Frenkel defect -colour centers - F center - other colour centers- Dislocations - Slip and plastic deformation - Shear strength of single crystals - Edge dislocation - Screw dislocation - Stress field around an edge dislocation.

UNIT - II

Theory of Semiconductors Intrinsic and extrinsic semiconductors - Free carrier concentration in semiconductors – Fermi level and carrier concentration in semiconductors – Mobility of charge carriers – Effect of temperature on mobility – electrical conductivity of semiconductors – Hall Effect in semiconductors – Junction properties.

Ultrasonics: Non destructive testing and applications.

UNIT - III

Theory of Dielectrics, Piezoelectrics and Ferroelectrics Dipole moment – Polarization – the electric field of a dipole – local electric field at an atom – Clausius –Mosotti equation - Dielectric constants and its measurements - Polarizability – The Classical theory of electronic polarizability – dipolar polarizability – Ferro electricity – Dipole theory of ferroelectricity – Piezoelectricity.

UNIT - IV

Heat capacity of the electron gas: Experimental electrical resistivity of metals – Free electron theory of metals – Debye's equation - superconductivity - Electron phonon interaction - Cooper pairs – BCS theory - Energy gap and its temperature dependence - London equation – Josephson effect and its applications.

Langevin theory of Para magnetism: Quantum theory of Para Magnetism - Curie law- Ferro Magnetism - Weiss molecular field theory - Domain theory - Anti Ferro magnetism -Neel theory - Ferri Magnetism – Ferrites – spin – waves - Experimental techniques to study the magnetic properties.

UNIT - V

Superconductivity Sources of superconductivity – The Meissner effect – Thermodynamics of superconducting transitions – Origin of energy gap – London equations –London Penteration depth – Type I and Type II Sueprconductors - Coherence length – BCS theory – Flux quantization – Theory of DC and AC Josephesen effect – Potential applications of superconductivity.

TEXT BOOKS:

1. Kittel. C. 2005, Introduction to Solid State Physics, 8th Edition, Willey Eastern Ltd., New Delhi.
2. Saxena. B.S., R.C.Gupta and P.N.Saxena, 2012, Fundamentals of Solid State Physics, 15th edition, Pragati Prakashan, Meeru.

REFERENCES

1. Dekkar. A.J., revised edition, 2000, Solid State Physics, Macmillan India Ltd., New Delhi.
2. Keer. H.V. 1st edition , 2002, Principles of Solid State, New age international., New Delhi.
3. Pillai S.O., 2005, Solid State Physics, 4th Edition, New Age International Publishers Ltd.

UNIT-I

SYLLABUS

Inter planar spacing: Inter planar spacing for SC, FCC, BCC lattices - diamond cubic structure - NaCl structure - The reciprocal lattice and their properties - Bragg condition in terms of reciprocal lattice.
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INTER PLANAR SPACING FOR SC, FCC, BCC LATTICES

The spacing between planes in a family with the Miller indices h, k and l is denoted by dhkl. A formula relating this distance to the Miller indices and the lattice constant (a) exists for each crystal system. The equation for a cubic system is:

(1/dhkl)2 = (h2 + k2 + l2) ÷ a2

For other systems, the relationship is more complicated because you need to define for parameters to isolate a particular plane. For example, the equation for a tetragonal system is:

(1/dhkl)2 = [(h2 + k2)/a2] + l2/c2, where c is the intercept on the z-axis.

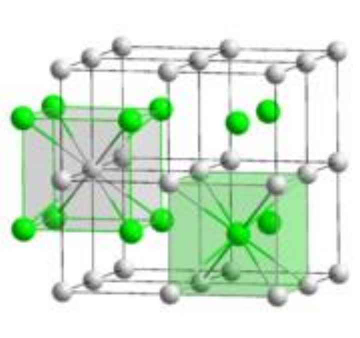
SIMPLE CRYSTAL STRUCTURES

Cesium chloride

Cesium chloride is the inorganic compound with the formula CsCl. This colorless solid is an important source of cesium ions in a variety of applications. Its crystal structure forms a major structural type where each cesium ion is coordinated by 8 chlorine ions. Cesium chloride crystals are thermally stable, but easily dissolve in water and concentrated hydrochloric acid, and therefore gradually disintegrate in the ambient conditions due to moisture. Cesium chloride occurs naturally in mineral waters and as an impurity in carnallite (up to 0.002%), sylvite andkainite. Less than 20 tonnes of CsCl is produced annually worldwide, mostly from a cesium-bearing mineral pollucite.

Cesium chloride is widely used in isopycnic centrifugation for separating various types of DNA. It is a reagent in analytical chemistry, where it is used to identify ions by the color and morphology of the precipitate. When enriched in radioisotopes, such as ^{137}CsCl or ^{131}CsCl, cesium chloride is used in nuclear medicine applications such as treatment of cancer and diagnosis of myocardial infarction. Another form of cancer treatment was studied using conventional non-radioactive CsCl. Whereas conventional cesium chloride has a rather low toxicity to humans and animals, the radioactive form easily contaminates the environment due to the high solubility of CsCl in water. Spread of ^{137}CsCl powder from a 93-gram container in 1987 in Goiânia, Brazil, resulted in one of the worst-ever radiation spill accidents killing four and directly affecting more than 100,000 people.

Crystal structure



Ball-and-stick model of the coordination of Cs and Cl in CsCl

The cesium chloride structure adopts a primitive cubic lattice with a two-atom basis, where both atoms have eightfold coordination. The chloride atoms lie upon the lattice points at the edges of the cube, while the cesium atoms lie in the holes in the center of the cubes. This structure is shared with CsBr and CsI and many binary metallic alloys. In contrast, the other alkaline halides have the sodium chloride (rocksalt) structure. When both ions are similar in size (Cs^+ ionic radius 174 pm for this coordination number, Cl^- 181 pm) the CsCl structure is adopted, when they are different (Na^+ ionic radius 102 pm, Cl^- 181 pm) the sodium chloride structure is adopted. Upon heating to above 450 °C, the normal cesium chloride structure (α-CsCl) converts to the β-CsCl form with the rocksalt structure (space group*Fm3m*).

Uses

Precursor to Cs metal

Cesium chloride is the main precursor to cesium metal by high temperature reduction:

$2\ CsCl + Mg \rightarrow MgCl_2 + Cs$

An analogous reaction – heating CsCl with calcium in vacuum in presence of phosphorus was first reported in 1905 by the French chemist M. L. Hackspill and is still used industrially.

Cesium hydroxide is obtained by electrolysis of aqueous cesium chloride solution:

$2\ CsCl + 2\ H_2O \rightarrow 2\ CsOH + Cl_2 + H_2$

Solute for ultracentrifugation

Cesium chloride is widely used in centrifugation in a technique known as isopycnic centrifugation. Centripetal and diffusive forces establish a density gradient that allow separation of mixtures on the basis of their molecular density. This technique allows separation of DNA of different densities (e.g. DNA fragments with differing A-T or G-C content). This application requires a solution with high density and yet relatively low viscosity, and CsCl suits it because of its high solubility in water, high density owing to the large mass of Cs, as well as low viscosity and high stability of CsCl solutions.

Medicine

Medical properties of cesium chloride were studied back in 1888 by Ivan Pavlov and S. S. Botkin. They found that CsCl and RbCl induce long-term narrowing of the blood vessels (vasoconstriction) and the associated increase in the blood pressure (hypertension), stimulating the cardiovascular activity. These properties were then applied in the treatment of cardiovascular deceases.

Later research indicated that CsCl alleviates cardiac dysrhythmia and that the life expectancy is higher in regions characterized by elevated levels of CsCl in water and food. Preliminary results indicate that CsCl can be used in the treatment of depressions. The neurological action of CsCl is related to the protection of neurons from apoptosis and activation of caspase 3 caused by reduced potassium content.

Several reports suggested that non-radioactive cesium chloride can be used in a complex treatment of some forms of cancer. However, it has been linked to the deaths of over 50 patients, when it was used as part of a scientifically unvalidated cancer treatment. The American Cancer Society considers cesium chloride therapy as requiring a further study for benefits and side effects.

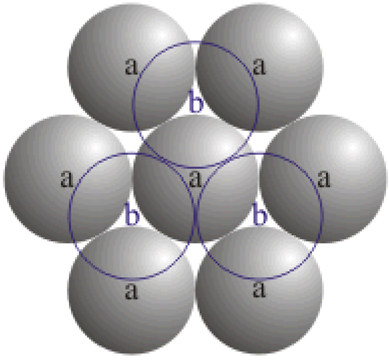
NUCLEAR MEDICINE AND RADIOGRAPHY

Cesium chloride composed of radioisotopes such as ^{137}CsCl and ^{131}CsCl, is used in nuclear medicine, including treatment of cancer(brachytherapy) and diagnosis of myocardial infarction. In the production of radioactive sources, it is normal to choose a chemical form of the radioisotope which would not be readily dispersed in the environment in the event of an accident. For instance, radiothermal generators (RTGs) often use strontium titanate, which is insoluble in water. For teletherapy sources, however, the radioactive density (Ci in a given volume) needs to be very high, which is not possible with known insoluble cesium compounds. A thimble-shaped container of radioactive cesium chloride provides the active source.

APPLICATIONS

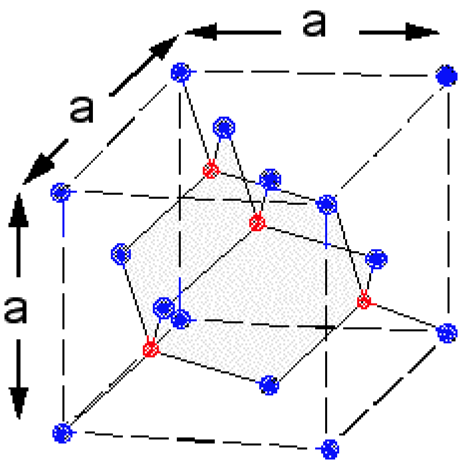
Cesium chloride is used in the preparation of electrically conducting glasses and screens of cathode ray tubes. It is a non-toxic provider of a halogen gas in exciplex lamps (exilamps) – a gas-discharge source of ultraviolet light which uses, for example, electrically excited XeCl molecules. Other uses include activation of electrodes in welding; manufacture of mineral water, beer and drilling muds; repellents and high-temperature solders. High-quality CsCl single crystals have a wide transparency range from UV to the infrared and therefore had been used for cuvettes, prisms and windows in optical spectrometers; this use was discontinued with the development of less hygroscopic materials.

HEXAGONAL CLOSE-PACKED STRUCTURE



In a hexagonal close-packed (hcp) arrangement of atoms, the unit cell consists of three layers of atoms. The top and bottom layers (*a*) contain six atoms at the corners of a hexagon and one atom at the center of each hexagon. The middle layer (*b*) contains three atoms nestled between the atoms of the top and bottom layers, hence, the name close-packed. The hexagonal close packed structure can be made by piling layers in the *a-b-a-b-a-b...* sequence.

CUBIC ZINC SULPHIDE STRUCTURE



Zinc sulfide (or zinc sulphide) is a inorganic compound with the formula ZnS. ZnS is the main form of zinc in nature, where it mainly occurs as the mineral sphalerite. Although the mineral is black owing to impurities, the pure material is white and is in fact used widely as a pigment.

STRUCTURE OF ZnS

ZnS exists in two main forms, and this dualism is often a textbook example of polymorphism. In both polymorphs, the coordination geometry at Zn and S are tetrahedral. The more stable form cubic form is known also as zinc blende or sphalerite. The hexagonal form is known as the mineral wurtzite, although it also can be produced synthetically. The transition from the sphalerite form to the wurtzite form occurs at around 1020 °C. A tetragonal form is also known as the very rare mineral called polhemusite, with the formula (Zn,Hg)S.

APPLICATIONS

Luminescent material

Zinc sulfide, with addition of few ppm of suitable activator, is used as phosphor in many applications, from cathode ray tubes through X-ray screens to glow in the dark products. When silver is used as activator, the resulting color is bright blue, with maximum at 450 nm. Manganese yields an orange-red color at around 590 nm. Copper provides long glow time and the familiar glow-in-the-dark greenish color. Copper-doped zinc sulfide ("ZnS+Cu") is used also in electroluminescent panels. It also exhibits phosphorescence due to impurities on illumination with blue or ultraviolet light.

Optical material

Zinc sulfide is also used as an infrared optical material, transmitting from visible wavelengths to over 12 micrometres. It can be used planar as an optical window or shaped into a lens. It is made as microcrystalline sheets by the synthesis from hydrogen sulfide gas and zinc vapour and sold as FLIR (Forward Looking IR) grade ZnS a pale milky yellow visibly opaque form. This material when hot isostatically pressed (HIPed) can be converted to a water-clear form known as Cleartran (trademark). Early commercial forms were marketed as Irtran-2 but this designation is now obsolete.

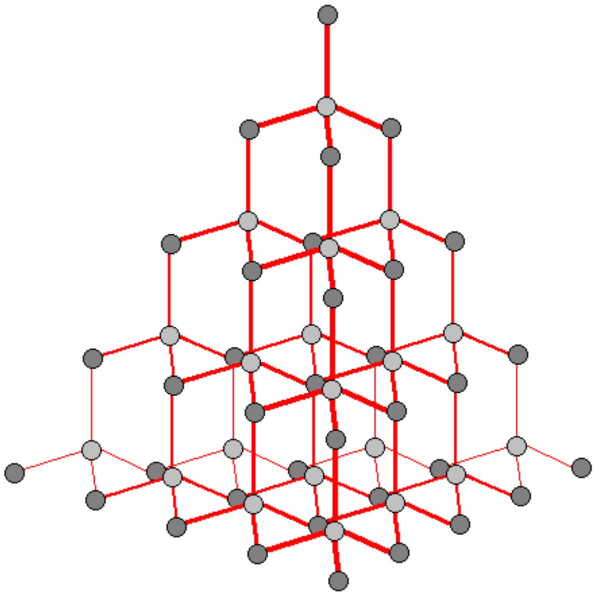
Pigment

Zinc sulfide is a common pigment. When compounded with barium sulfate, zinc sulfide form slithopone.

Semiconductor properties

Both sphalerite and wurtzite are intrinsic, wide-bandgap semiconductors. It is a prototypical II-VI semiconductor and adopts structures related to many other semiconductors such as gallium arsenide. The cubic form has a band gap of 3.54 eV at 300 K whereas the hexagonal form has a band gap of 3.91 eV. It can be doped as both n-type semiconductor and p-type semiconductor.

DIAMOND STRUCTURE



In mineralogy, diamond is an allotrope of carbon, where the carbon atoms are arranged in a variation of the face-centered cubic crystal structure called a diamond lattice. Diamond is less stable than graphite, but the conversion rate from diamond to graphite is negligible at ambient conditions. Diamond is renowned as a material with superlative physical qualities, most of which originate from the strong covalent bonding between its atoms. In particular, diamond has the highest hardness and thermal conductivity of any bulk material. Those properties determine the major industrial application of diamond in cutting and polishing tools.

Diamond has remarkable optical characteristics. Because of its extremely rigid lattice, it can be contaminated by very few types of impurities, such as boron and nitrogen. Combined with wide transparency, this results in the clear, colorless appearance of most natural diamonds. Small amounts of defects or impurities (about one per million of lattice atoms) color diamond blue (boron), yellow (nitrogen), brown (lattice defects), green (radiation exposure), purple, pink, orange or red. Diamond also has relatively high optical dispersion (ability to disperse light of different colors), which results in its characteristic luster. Excellent optical and mechanical properties, combined with efficient marketing, make diamond the most popular gemstone.

Most natural diamonds are formed at high-pressure high-temperature conditions existing at depths of 140 to 190 kilometers (87 to 120 mi) in the Earth mantle. Carbon-containing minerals provide the carbon source, and the growth occurs over periods from 1 billion to 3.3 billion years (25% to 75% of the age of the Earth). Diamonds are brought close to the Earth surface through deep volcanic eruptions by a magma, which cools into igneous rocks known as kimberlites and lamproites. Diamonds can also be produced synthetically in a high-pressure high-temperature process which approximately simulates the conditions in the Earth mantle. An alternative and completely different growth technique is chemical vapor deposition (CVD). Several non-diamond materials, which include cubic zirconia and silicon carbide and are often called diamond simulants, resemble diamond in appearance and many properties. Special gemological techniques have been developed to distinguish natural and synthetic diamonds and diamond simulants.

SODIUM CHLORIDE STRUCTURE

Sodium chloride, also known as salt, common salt, table salt or halite, is an ionic compound with the formula NaCl. Sodium chloride is the salt most responsible for the salinity of the ocean and of the extracellular fluid of many multicellular organisms. As the major ingredient in edible salt, it is commonly used as a condiment and food preservative.

Chemistry of solid and dissolved sodium chloride

Solid sodium chloride

In solid sodium chloride, each ion is surrounded by six ions of the opposite charge as expected on electrostatic grounds. The surrounding ions are located at the vertices of a regular octahedron. In the language of close-packing, the larger chloride ions are arranged in a cubic array whereas the smaller sodium ions fill all the cubic gaps (octahedral voids) between them. This same basic structure is found in many other compounds and is commonly known as the halite or rock-salt crystal structure. It can be represented as a face-centered cubic (fcc) lattice with a two-atom basis or as two interpenetrating face centered cubic lattices. The first atom is located at each lattice point, and the second atom is located half way between lattice points along the fcc unit cell edge.

Thermal conductivity of NaCl as a function of temperature has a maximum of 2.03 W/(cm K) at 8 K and decreases to 0.069 at 314 K (41 °C). It also decreases with doping.

Aqueous solutions

The attraction between the Na^+ and Cl^- ions in the solid is so strong that only highly polar solvents like water dissolve NaCl well.

When dissolved in water, the sodium chloride framework disintegrates as the Na^+ and Cl^- ions become surrounded by the polar water molecules. These solutions consist of metal aquo complex with the formula $[Na(H_2O)_x]^+$, where x is 8 with the Na-O distance of 250 pm. The chloride ions are also strongly solvated, each being surrounded by an average of 6 molecules of water. Solutions of sodium chloride have very different properties from pure water. The freezing point is −21.12 °C for 23.31 wt% of salt, and the boiling point of saturated salt solution is near 108.7 °C. From cold solutions, salt crystallizes as the dihydrate$NaCl\cdot 2H_2O$.

Uses

Chemicals production

Salt is the source, directly or indirectly, for the production of many chemicals, which consume most of the world's production.

Chlor-alkali industry

It is the starting point for the Chloralkali process, which provides the world with chlorine and sodium hydroxide according to the chemical equation:

$2\ NaCl + 2\ H_2O \rightarrow Cl_2 + H_2 + 2\ NaOH$

This electrolysis is conducted in either a mercury cell, a diaphragm cell, or a membrane cell. Each of those use a different method to separate the chlorine from the sodium hydroxide. Other technologies are under development due to the high energy consumption of the electrolysis, whereby small improvements in the efficiency can have large economic paybacks. Some application of chlorine includes PVC, disinfectants, and solvents. From sodium hydroxide enables industries that produce paper, soap, and aluminium.

Soda ash industry

Via the Solvay process, sodium chloride is used to produce sodium carbonate and calcium chloride. Sodium carbonate is used to produce glass, sodium bicarbonate, and dyes as well as myriad other chemicals. In the Mannheim process and in the Hargreaves process, it is used for the production of sodium sulfate and hydrochloric acid.

Industrial uses

Sodium chloride is heavily used, so even miscellaneous applications can consume massive quantities. In oil and gas exploration, salt is an important component of drilling fluids in well drilling. It is used to flocculate and increase the density of the drilling fluid to overcome high down well gas pressures. Whenever a drill hits a salt formation, salt is added to the drilling fluid to saturate the solution and to minimize the dissolution within the salt stratum. Salt is also used to increase the curing of concrete in cemented casings.

In textiles and dyeing, salt is used as a brine rinse to separate organic contaminants, to promote "salting out" of dyestuff precipitates, and to blend with concentrated dyes to standardize them. One of its main roles is to provide the positive ion charge to promote the absorption of negatively charged ions of dyes.

It also is used in processing aluminium, beryllium, copper, steel and vanadium. In the pulp and paper industry, salt is used to bleach wood pulp. It also is used to make sodium chlorate, which is added along with sulfuric acid and water to manufacture chlorine dioxide, an excellent oxygen-based bleaching chemical. The chlorine dioxide process, which originated in Germany after World War I, is becoming more popular because of environmental pressures to reduce or eliminate chlorinated bleaching compounds. In tanning and leather treatment, salt is added to animal hides to inhibit microbial activity on the underside of the hides and to attract moisture back into the hides.

In rubber manufacture, salt is used to make buna, neoprene and white rubber types. Salt brine and sulfuric acid are used to coagulate an emulsified latex made from chlorinated butadiene.

Salt also is added to secure the soil and to provide firmness to the foundation on which highways are built. The salt acts to minimize the effects of shifting caused in the subsurface by changes in humidity and traffic load.

Water softening

Hard water contains calcium and magnesium ions that interfere with action of soap and contribute to the buildup of a scale or film of alkaline mineral deposits in household and industrial equipment and pipes. Commercial and residential water-softening units use ion exchange resins to remove the offending ions that cause the hardness. These resins are generated and regenerated using sodium chloride.

Road salt

The second major application of salt is for deicing and anti-icing of roads, both in grit bins and spread by winter service vehicles. In anticipation of snowfall, roads are optimally "anti-iced" with brine (concentrated solution of salt in water), which prevents bonding between the snow-ice and the road surface. This procedure precludes the heavy use of salt after the snowfall. For de-icing, mixtures of brine and salt are used, sometimes with additional agents such as calcium and magnesium chloride. The use of salt or brine becomes ineffective below -10 °C.

Salt for de-icing in the United Kingdom predominantly comes from a single mine in Winsford in Cheshire. Prior to distribution it is mixed with <100 ppm of sodium hexacyanoferrate (II) as an anti-caking agent, which enables rock salt to flow freely out of the gritting vehicles despite being stockpiled prior to use. In recent years this additive has also been used in table salt. Other additives had been used in road salt to reduce the total costs. For example, in the US, a byproduct carbohydrate solution from sugar beet processing was mixed with rock salt and adhered to road surfaces about 40% better than loose rock salt alone. Because it stayed on the road longer, the treatment did not have to be repeated several times, saving time and money.

In the technical terms of physical chemistry, the minimum freezing point of a water-salt mixture is −21.12 °C for 23.31 wt% of salt. Freezing near this concentration is however so slow that the eutectic point of −22.4 °C can be reached with about 25 wt% of salt.

Environmental effect

Road salt ends up in fresh water bodies and could harm aquatic plants and animals by disrupting their osmoregulation ability. The omnipresence of salt poses a problem in any coastal coating application, as trapped salts cause great problems in adhesion. Naval authorities and ship builders monitor the salt concentrations on surfaces during construction. Maximum salt concentrations on surfaces are dependent on the authority and application. The IMO regulation is mostly used and sets salt levels to a maximum of 50 mg/m^2 soluble salts measured as sodium chloride. These measurements are done by means of a Bresle test.

In highway deicing, salt has been associated with corrosion of bridge decks, motor vehicles, reinforcement bar and wire, and unprotected steel structures used in road construction. Surface runoff, vehicle spraying, and windblown actions also affect soil, roadside vegetation, and local surface water and groundwater supplies. Although evidence of environmental loading of salt has been found during peak usage, the spring rains and thaws usually dilute the concentrations of sodium in the area where salt was applied.

Food industry, medicine and agriculture

Many micro organisms cannot live in an overly salty environment: water is drawn out of their cells by osmosis. For this reason salt is used to preserve some foods, such as smoked bacon or fish. It can also be used to detach leeches that have attached themselves to feed. It is also used to disinfect wounds.

Salt is added in most food items, by the food processor or by the consumer, as a flavor enhancer, preservative, binder, fermentation-control additive, texture-control agent and color developer. The salt consumption in the food industry is subdivided, in descending order of consumption, into other food processing, meat packers, canning, baking, dairy and grain mill products. Salt is added to promote color development in bacon, ham and other processed meat products. As a preservative, salt inhibits the growth of bacteria. Salt acts as a binder in sausages to form a binding gel made up of meat, fat, and moisture. Salt also acts as a flavor enhancer and as a tenderizer.

In the dairy industry, salt is added to cheese as a color-, fermentation-, and texture-control agent. The dairy subsector includes companies that manufacture creamery butter, condensed and evaporated milk, frozen desserts, ice cream, natural and processed cheese, and specialty dairy products. In canning, salt is primarily added as a flavor enhancer and preservative. It also is used as a carrier for other ingredients, dehydrating agent, enzyme inhibitor and tenderizer. In baking, salt is added to control the rate of fermentation in bread dough. It also is used to strengthen the gluten (the elastic protein-water complex in certain doughs) and as a flavor enhancer, such as a topping on baked goods. The food-processing category also contains grain mill products. These products consist of milling flour and rice and manufacturing cereal breakfast food and blended or prepared flour. Salt is also used a seasoning agent, e.g. in potato chips, pretzels, cat and dog food.

Sodium chloride is used in veterinary medicine as emesis causing agent. It is given as warm saturated solution. Emesis can also be caused by pharyngeal placement of small amount of plain salt or salt crystals.

Fire fighting

Sodium chloride is the principal extinguishing agent in fire extinguishers (Met-L-X, Super D) used on combustible metal fires such as magnesium, potassium, sodium, and NaK alloys (Class D). Thermoplastic powder is added to the mixture, along with waterproofing (metal stearates) and anti-caking materials (tricalcium phosphate) to form the extinguishing agent. When it is applied to the fire, the salt acts like a heat sink, dissipating heat from the fire, and also forms an oxygen-excluding crust to smother the fire. The plastic additive melts and helps the crust maintain its integrity until the burning metal cools below its ignition temperature. This type of extinguisher was invented in the late 1940s in the cartridge-operated type shown here, although stored pressure versions are now popular. Common sizes are 30 lb portable and 350 lb wheeled.

Cleanser

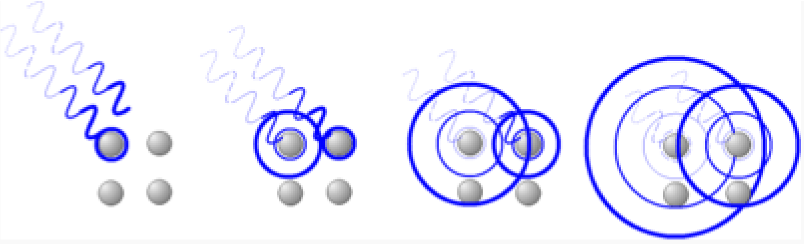
Since at least medieval times, people have used salt as a cleansing agent rubbed on household surfaces. It is also used in many brands of shampoo, toothpaste and popularly to de-ice driveways and patches of ice.

DIFFRACTION OF WAVES BY CRYSTALS: BRAGG'S LAW

In physics, Bragg's law gives the angles for coherent and incoherent scattering from a crystal lattice. When X-rays are incident on an atom, they make the electronic cloud move as does any electromagnetic wave. The movement of these charges re-radiates waves with the same frequency (blurred slightly due to a variety of effects); this phenomenon is known as Rayleigh scattering (or elastic scattering). The scattered waves can themselves be scattered but this secondary scattering is assumed to be negligible.

A similar process occurs upon scattering neutron waves from the nuclei or by a coherent spin interaction with an unpaired electron. These re-emitted wave fields interfere with each other either constructively or destructively (overlapping waves either add together to produce stronger peaks or subtract from each other to some degree), producing a diffraction pattern on a detector or film. The resulting wave interference pattern is the basis of diffraction analysis. This analysis is called *Bragg diffraction*.

Bragg diffraction (also referred to as the Bragg formulation of X-ray diffraction) was first proposed by William Lawrence Bragg and William Henry Bragg in 1913 in response to their discovery that crystalline solids produced surprising patterns of reflected X-rays (in contrast to that of, say, a liquid). They found that these crystals, at certain specific wavelengths and incident angles, produced intense peaks of reflected radiation (known as *Bragg peaks*). The concept of Bragg diffraction applies equally to neutron diffraction and electron diffraction processes. Both neutron and X-ray wavelengths are comparable with inter-atomic distances (~150 pm) and thus are an excellent probe for this length scale.

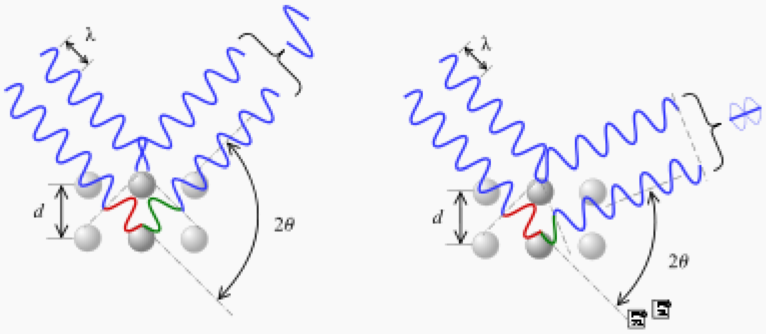


X-rays interact with the atoms in a crystal.

W. L. Bragg explained this result by modeling the crystal as a set of discrete parallel planes separated by a constant parameter *d*. It was proposed that the incident X-ray radiation would produce a Bragg peak if their reflections off the various planes interfered constructively. The interference is constructive when the phase shift is a multiple of 2π; this condition can be expressed by Bragg's law,

$$n\lambda = 2d\sin\theta$$

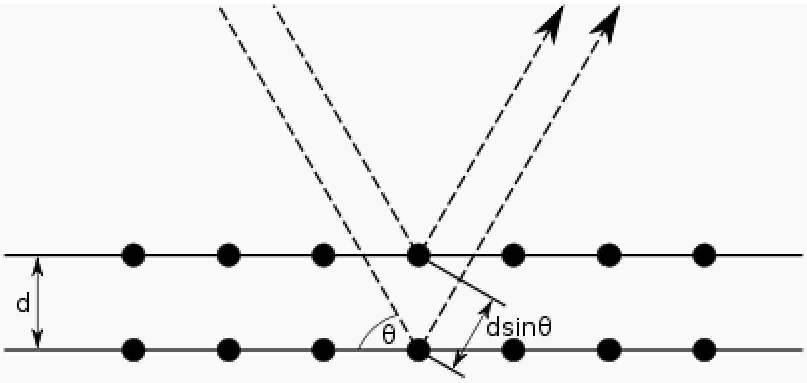
Where *n* is an integer, *λ* is the wavelength of incident wave, *d* is the spacing between the planes in the atomic lattice, and *θ* is the angle between the incident ray and the scattering planes. Note that moving particles, including electrons, protons and neutrons, have an associated De Broglie wavelength.



According to the 2*θ* deviation, the phase shift causes constructive (left figure) or destructive (right figure) interferences.

Bragg's Law was derived by physicist Sir William Lawrence Bragg in 1912 and first presented on 11 November 1912 to the Cambridge Philosophical Society. Although simple, Bragg's law confirmed the existence of real particles at the atomic scale, as well as providing a powerful new tool for studying crystals in the form of X-ray and neutron diffraction. William Lawrence Bragg and his father, Sir William Henry Bragg, were awarded the Nobel Prize in physics in 1915 for their work in determining crystal structures beginning with NaCl, ZnS, and diamond. They are the only father-son team to jointly win. W. L. Bragg was 25 years old, making him the youngest Nobel laureate.

Bragg condition



Bragg diffraction. Two beams with identical wavelength and phase approach a crystalline solid and are scattered off two different atoms within it. The lower beam traverses an extra length of $2d\sin\theta$. Constructive interference occurs when this length is equal to an integer multiple of the wavelength of the radiation.

Bragg diffraction occurs when electromagnetic radiation or subatomic particle waves with wavelength comparable to atomic spacings are incident upon a crystalline sample, are scattered in a specular fashion by the atoms in the system, and undergo constructive interference in accordance to Bragg's law. For a crystalline solid, the waves are scattered from lattice planes separated by the interplanar distance d. Where the scattered waves interfere constructively, they remain in phase since the path length of each wave is equal to an integer multiple of the wavelength. The path difference between two waves undergoing constructive interference is given by $2d\sin\theta$, where θ is the scattering angle. This leads to Bragg's law, which describes the condition for constructive interference from successive crystallographic planes (h, k, and l, as given in Miller Notation) of the crystalline lattice:

$$2d\sin\theta = n\lambda,$$

where *n* is an integer determined by the order given, and *λ* is the wavelength. A diffraction pattern is obtained by measuring the intensity of scattered waves as a function of scattering angle. Very strong intensities known as Bragg peaks are obtained in the diffraction pattern when scattered waves satisfy the Bragg condition.

RECIPROCAL LATTICE VECTORS

In physics, the reciprocal lattice of a lattice (usually a Bravais lattice) is the lattice in which the Fourier transform of the spatial function of the original lattice (or *direct lattice*) is represented. This space is also known as *momentum space* or less commonly *k-space*, due to the relationship between the Pontryagin duals momentum and position. The reciprocal lattice of a reciprocal lattice is the original or *direct lattice*.

Mathematical description

Consider a set of points R constituting a Bravais lattice, and a plane wave defined by:

$$e^{i\mathbf{K}\cdot\mathbf{r}} = \cos\left(\mathbf{K}\cdot\mathbf{r}\right) + i\sin\left(\mathbf{K}\cdot\mathbf{r}\right)$$

If this plane wave has the same periodicity as the Bravais lattice, then it satisfies the equation:

$$e^{i\mathbf{K}\cdot(\mathbf{r}+\mathbf{R})} = e^{i\mathbf{K}\cdot\mathbf{r}}$$
$$\therefore e^{i\mathbf{K}\cdot\mathbf{r}}e^{i\mathbf{K}\cdot\mathbf{R}} = e^{i\mathbf{K}\cdot\mathbf{r}}$$
$$\Rightarrow e^{i\mathbf{K}\cdot\mathbf{R}} = 1$$

Mathematically, we can describe the reciprocal lattice as the set of all vectors K that satisfy the above identity for all lattice point position vectors R. This reciprocal lattice is itself a Bravais lattice, and the reciprocal of the reciprocal lattice is the original lattice, which reveals the Pontryagin duality of their respective vector spaces.

For an infinite three dimensional lattice, defined by its primitive vectors $(\mathbf{a_1}, \mathbf{a_2}, \mathbf{a_3})$, its reciprocal lattice can be determined by generating its three reciprocal primitive vectors, through the formulae

$$\mathbf{b}_1 = 2\pi \frac{\mathbf{a}_2 \times \mathbf{a}_3}{\mathbf{a}_1 \cdot (\mathbf{a}_2 \times \mathbf{a}_3)}$$

$$\mathbf{b}_2 = 2\pi \frac{\mathbf{a}_3 \times \mathbf{a}_1}{\mathbf{a}_1 \cdot (\mathbf{a}_2 \times \mathbf{a}_3)}$$

$$\mathbf{b}_3 = 2\pi \frac{\mathbf{a}_1 \times \mathbf{a}_2}{\mathbf{a}_1 \cdot (\mathbf{a}_2 \times \mathbf{a}_3)}$$

Note that the denominator is the scalar triple product. Using column vector representation of (reciprocal) primitive vectors, the formulae above can be rewritten using matrix inversion:

$$\left[\mathbf{b}_1 \mathbf{b}_2 \mathbf{b}_3\right]^T = 2\pi \left[\mathbf{a}_1 \mathbf{a}_2 \mathbf{a}_3\right]^{-1}.$$

This method appeals to the definition, and allows generalization to arbitrary dimensions. The cross product formula dominates introductory materials on crystallography.

The above definition is called the "physics" definition, as the factor of 2π comes naturally from the study of periodic structures. An equivalent definition, the "crystallographer's" definition, comes from defining the reciprocal lattice to be $e^{2\pi i \mathbf{K}\cdot\mathbf{R}} = 1$ which changes the definitions of the reciprocal lattice vectors to be

$$\mathbf{b}_1 = \frac{\mathbf{a}_2 \times \mathbf{a}_3}{\mathbf{a}_1 \cdot (\mathbf{a}_2 \times \mathbf{a}_3)}$$

and so on for the other vectors. The crystallographer's definition has the advantage that the definition of $\mathbf{b}_1$ is just the reciprocal magnitude of $\mathbf{a}_1$ in the direction of $\mathbf{a}_2 \times \mathbf{a}_3$, dropping the factor of 2π. This can simplify certain mathematical manipulations, and expresses reciprocal lattice dimensions in units of spatial frequency. It is a matter of taste which definition of the lattice is used, as long as the two are not mixed.

Each point (hkl) in the reciprocal lattice corresponds to a set of lattice planes (hkl) in the real space lattice. The direction of the reciprocal lattice vector corresponds to the normal to the real space planes. The magnitude of the reciprocal lattice vector is given in reciprocal length and is equal to the reciprocal of the interplanar spacing of the real space planes.

The reciprocal lattice plays a fundamental role in most analytic studies of periodic structures, particularly in the theory of diffraction. For Bragg reflections in neutron and X-ray diffraction, the momentum difference between incoming and diffracted X-rays of a crystal is a reciprocal lattice vector. The diffraction pattern of a crystal can be used to determine the reciprocal vectors of the lattice. Using this process, one can infer the atomic arrangement of a crystal.

The Brillouin zone is a primitive unit cell of the reciprocal lattice.

Reciprocal lattice to Simple cubic lattice

The simple cubic Bravais lattice, with cubic primitive cell of side a, has for its reciprocal a simple cubic lattice with a cubic primitive cell of side $\frac{2\pi}{a}$ ($\frac{1}{a}$ in the crystallographer's definition). The cubic lattice is therefore said to be self-dual, having the same symmetry in reciprocal space as in real space.

Reciprocal lattice to Face-centered cubic (FCC) lattice

The reciprocal lattice to an FCC lattice is the body-centered cubic (BCC) lattice.

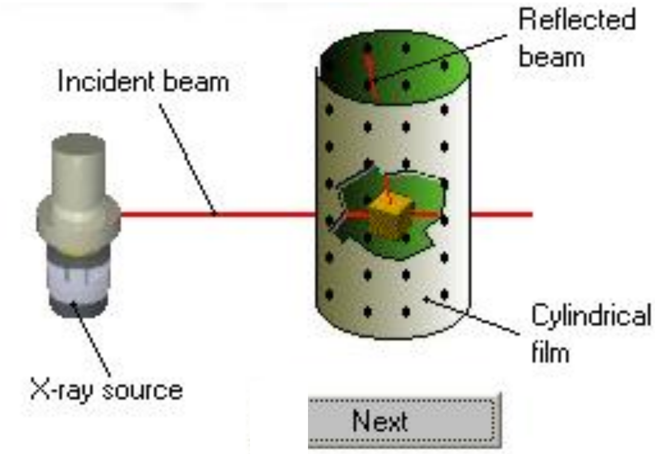
Consider an FCC compound unit cell. Locate a primitive unit cell of the FCC, i.e., a unit cell with one lattice point. Now take one of the vertices of the primitive unit cell as the origin. Give the basis vectors of the real lattice. Then from the known formulae you can calculate the basis vectors of the reciprocal lattice. These reciprocal lattice vectors of the FCC represent the basis vectors of a BCC real lattice. Note that the basis vectors of a real BCC lattice and the reciprocal lattice of an FCC resemble each other in direction but not in magnitude.

Reciprocal lattice to Body-centered cubic (BCC) lattice

The reciprocal lattice to a BCC lattice is the FCC lattice.

It can be easily proven that only the Bravais lattices which have 90 degrees between $(\mathbf{a}_1, \mathbf{a}_2, \mathbf{a}_3)$ (cubic, tetragonal, orthorhombic) have $(\mathbf{b}_1, \mathbf{b}_2, \mathbf{b}_3)$ parallel to their real-space vectors.

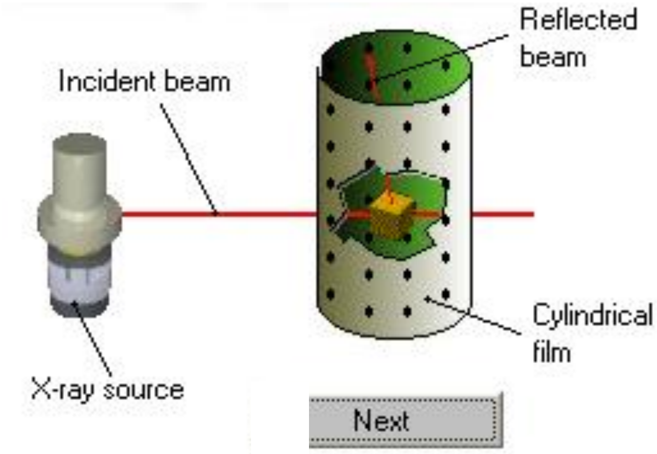
ROTATING CRYSTAL METHOD BY X-RAYS

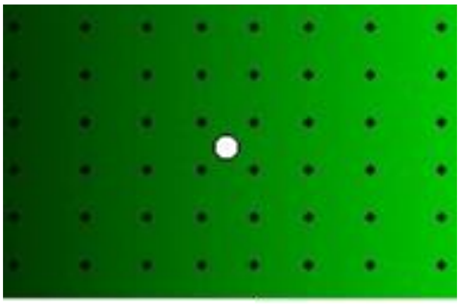


In the rotating crystal method, a single crystal is mounted with an axis normal to a monochromatic X-ray beam. A cylindrical film is placed around it and the crystal is rotated about the chosen axis. As the crystal rotates, sets of lattice planes will at some point make the correct Bragg angle for the monochromatic incident beam, and at that point a diffracted beam will be formed. Lattice constant of the crystal can be determined by means of this method; for a given wavelength if the angle at which a reflection occurs is known, can be determined.

$$d = \frac{a}{\sqrt{h^2 + k^2 + l^2}}$$

The reflected beams are located on the surface of imaginary cones. By recording the diffraction patterns (both angles and intensities) for various crystal orientations; one can determine the shape and size of unit cell as well as arrangement of atoms inside the cell.





NEUTRON DIFFRACTION EXPERIMENT

Neutron diffraction or elastic neutron scattering is the application of neutron scattering to the determination of the atomic and/or magnetic structure of a material: A sample to be examined is placed in a beam of thermal or cold neutrons to obtain a diffraction pattern that provides information of the structure of the material. The technique is similar to X-ray diffraction but due to the different scattering properties of neutrons versus x-rays complementary information can be obtained.

PRINCIPLE

Neutrons are particles found in the atomic nucleus of almost all atoms, but they are bound. The technique requires free neutrons and these normally do not occur in nature, because they have limited life-time. In a nuclear reactor, however, neutrons can be set free through nuclear decay particularly when fission occurs. All quantum particles can exhibit wave phenomena we typically associate with light or sound. Diffraction is one of these phenomena; it occurs when waves encounter obstacles whose size is comparable with the wavelength. If the wavelength of a quantum particle is short enough, atoms or their nuclei can serve as diffraction obstacles. When a beam of neutrons emanating from a reactor is slowed down and selected properly by their speed, their wavelength lies near one angstrom (0.1 nanometer), the typical separation between atoms in a solid material. Such a beam can then be used to perform a diffraction experiment. Impinging on a crystalline sample it will scatter under a limited number of well-defined angles according to the same Bragg's law that describes X-ray diffraction.

Instrumental requirements

A neutron diffraction measurement requires a neutron source (e.g. a nuclear reactor or spallation source), a sample (the material to be studied), and a detector. Samples sizes are large compared to those used in X-ray diffraction. The technique is therefore mostly performed as powder diffraction. At a research reactor other components such as crystal monochromators or filters may be needed to select the desired neutron wavelength. Some parts of the setup may also be movable. At a spallation source the time of flight technique is used to sort the energies of the incident neutrons (Higher energy neutrons are faster), so no monochromator is needed, but rather a series of aperture elements synchronized to filter neutron pulses with the desired wavelength.

Nuclear scattering

Neutrons interact with matter differently than X-rays. X-rays interact primarily with the electron cloud surrounding each atom. The contribution to the diffracted x-ray intensity is therefore larger for atoms with a large atomic number (Z) than it is for atoms with a small Z. On the other hand, neutrons interact directly with the *nucleus* of the atom, and the contribution to the diffracted intensity is different for each isotope; for example, regular hydrogen and deuterium contribute differently. It is also often the case that light (low Z) atoms contribute strongly to the diffracted intensity even in the presence of large Z atoms. The scattering length varies from isotope to isotope rather than linearly with the atomic number. An element like vanadium is a strong scatterer of X-rays, but its nuclei hardly scatter neutrons, which is why it often used as a container material. Non-magnetic neutron diffraction is directly sensitive to the positions of the nuclei of the atoms.

A major difference with X-rays is that the scattering is mostly due to the tiny nuclei of the atoms. That means that there is no need for anatomic form factor to describe the shape of the electron cloud of the atom and the scattering power of an atom does not fall off with the scattering angle as it does for X-rays. Diffractograms therefore can show strong well defined diffraction peaks even at high angles, particularly if the experiment is done at low temperatures. Many neutron sources are equipped with liquid helium cooling systems that allow data collection at temperatures down to 4.2 K. The superb high angle (i.e. high *resolution*) information means that the data can give very precise values for the atomic positions in the structure. On the other hand, Fourier maps (and to a lesser extent difference Fourier maps) derived from neutron data suffer from series termination errors, sometimes so much that the results are meaningless.

Magnetic scattering

Although neutrons are uncharged, they carry a spin, and therefore interact with magnetic moments, including those arising from the electron cloud around an atom. Neutron diffraction can therefore reveal the microscopic magnetic structure of a material.

Magnetic scattering does require an atomic form factor as it is caused by the much larger electron cloud around the tiny nucleus. The intensity of the magnetic contribution to the diffraction peaks will therefore dwindle towards higher angles.

Uses

Neutron diffraction can be used to determine the static structure factor of gases, liquids or amorphous solids. Most experiments, however, aim at the structure of crystalline solids, making neutron diffraction an important tool of crystallography.

Neutron diffraction is closely related to X-ray powder diffraction. In fact the single crystal version of the technique is less commonly used because currently available neutron sources require relatively large samples and large single crystals are hard or impossible to come by for most materials. Future developments, however, may well change this picture. Because the data is typically a 1D powder diffractogram they are usually processed using Rietveld refinement. In fact the latter found its origin in neutron diffraction (at Petten in the Netherlands) and was later extended for use in X-ray diffraction.

One practical application of elastic neutron scattering/diffraction is that the lattice constant of metals and other crystalline materials can be very accurately measured. Together with an accurately aligned micropositioner a map of the lattice constant through the metal can be derived. This can easily be converted to the stress field experienced by the material. This has been used to analyze stresses in aerospace and automotive components to give just two examples. This technique has led to the development of dedicated stress diffractometers, such as the ENGIN-X instrument at the ISIS neutron source.

Neutron Diffraction can also be employed to give insight into the 3D structure of novel molecules such as Nanoparticles, Nanorods, Nanotubes, Fullerenes.

Hydrogen, null-scattering and contrast variation

Neutron diffraction can be used to establish the structure of low atomic number materials like proteins and surfactants much more easily with lower flux than at a synchrotron radiation source. This is because some low atomic number materials have a higher cross section for neutron interaction than higher atomic weight materials.

One major advantage of neutron diffraction over X-ray diffraction is that the latter is rather insensitive to the presence of hydrogen (H) in a structure, whereas the nuclei ^{1}H and ^{2}H (i.e. Deuterium, D) are strong scatterers for neutrons. This means that the position of hydrogen in a crystal structure and its thermal motions can be determined far more precisely with neutrons. In addition the neutron scattering lengths $b_H = -3.7406(11)$ fm and $b_D = 6.671(4)$ fm, for H and D respectively, have opposite sign allowing for contrast variation. In fact there is a particular isotope ratio for which the contribution of the element would cancel; this is called null-scattering. In practice however it is not desirable to work with the relatively high concentration of H in such a sample. The scattering intensity by H-nuclei has a large inelastic component and this creates a large continuous background that is more or less independent of scattering angle. The elastic pattern typically consists of sharp Bragg reflections if the sample is crystalline. They tend to drown in the inelastic background. This is even more serious when the technique is used for the study of liquid structure. Nevertheless, by preparing samples with different isotope ratios it is possible to vary the scattering contrast enough to highlight one element in an otherwise complicated structure. The variation of other elements is possible but usually rather expensive. Hydrogen is inexpensive and particularly interesting because it plays an exceptionally large role in biochemical structures and is difficult to study structurally in other ways.

LATTICE

ACOUSTIC AND OPTICAL BRANCHES

Many solid materials, including all metals, are composed of atoms arranged in a lattice arrangement called crystals. There are a variety of crystal structures like cubic, hexagonal, cubic with an atom in the center of the cube, called body centered cubic, cubic with an atom in the center of each face of the cube, called face centered cubic, and others. The particular structure depends on the relative sizes of the atoms that are nestled together to form the crystal. The reason that materials take crystal form is that these neat geometrical structures represent the lowest energy configuration of the collection of atoms making up the material. To dislodge an atom from the crystal structure requires the addition of energy.

Theoretically, at a temperature of absolute zero, the atoms of a crystal lie at their lowest energy position without moving at all. As thermal energy is added to the crystal it is manifest by vibration of the atoms about this equilibrium location. Within the limits of fairly small vibrations the electric forces bonding the atoms together stretch or compress a bit to a higher energy configuration. Each atom acts as though it were connected to its neighbors by little springs. The added energy is stored in the crystal as the kinetic energy of the atoms in motion and the potential energy of the compressed or stretched springs.

Let us consider the oscillation of the atoms in one-dimensional crystal simulated by the chain of the balls with the masses m_1 and m_2. The force applied to every atom depends upon the relative displacement of the nearby atoms and stiffness c of the virtual springs. Therefore, the displacement u of every atom in one-dimensional crystal is described by the equations:

$$\begin{cases} m_1\ddot{u}_n = -\chi(2u_n - u_{m-1} - u_m) \\ m_2\ddot{u}_m = -\chi(2u_m - u_n - u_{n+1}) \end{cases}$$

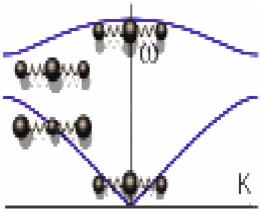
These equations determine the oscillatory motion of the atoms:

$$\begin{cases} u_n = A_1 \exp(i(kan - \omega t)) \\ u_m = A_2 \exp(i(kam - \omega t)) \end{cases}$$

where $a/2$ is the distance between the nearest atoms; k=2p/l is the wave factor, l is the wavelength of the wave in crystal. The equations mentioned above have two solutions for w :

$$\omega_1^2 = \frac{\omega_0^2}{2}\left(1 - \sqrt{1 - \gamma^2 \sin^2(ak/2)}\right) - \text{acoustic branch}$$
$$\omega_2^2 = \frac{\omega_0^2}{2}\left(1 + \sqrt{1 - \gamma^2 \sin^2(ak/2)}\right) - \text{optical branch}$$

where $g^2 = 4m_1m_2/(m_1+m_2)^2$; $w_0^2 = 2c\,(m_1+m_2)/m_1m_2$. These equations determine two branches of the dispersion curve (so called acoustic and optical branches).



Let us consider the types of oscillation in a crystal for these two branches. In the case of the long-wave approximation ($ak << 1$) in acoustic branch the atoms move synchronously and deviation of every atom is about the same at any moment of the time (see this case at the bottom of the animation); in optical branch the atoms move in antiphase (it is shown on top of animation). For the shortest waves ($k = 2\pi/\lambda = 2\pi/a$) in acoustic branch the lighter atoms are still and more heavy atoms oscillate; in the optical branch the situation is inverse (these cases are shown in the middle of animation). Oscillation of atoms in optical branch polarizes the matter electrically and this type of oscillation can be excited by infra-red optical radiation. This is the reason why this branch was called "optical". We can see that the modes differ in the details of how the atoms move, but they both represent energy stored in the crystal, being passed back and forth between the kinetic energy of the atoms and the potential energy of the "springs". The temperature of the crystal is proportional to the average kinetic energy of the atoms.

There are some limitations to this mechanical description of what is going on in crystal vibrations. Because we are dealing with objects as small as individual atoms, quantum mechanical effects may not be neglected. For example, in a metal sample large enough to work with in a laboratory, there may be millions of individual crystals each with millions of individual atoms. On a laboratory size scale, it appears that we can add energy to the sample in any amount, as if the crystal were really composed of weights and springs. In fact, energy may only be added in multiples of some minimum amount. We call that minimum amount of vibrational energy a "phonon" analogous to the photon energy packet familiar in electromagnetic radiation. Energy addition appears continuous on the laboratory scale because the phonon is so small. On the scale of the atoms in the crystals however, the phonon magnitude is significant and only vibration modes and amplitudes which differ in energy by whole phonon multiples are allowed.

SEMI CONDUCTORS AND THEIR PROPERTIES

A semiconductor is a substance, usually a solid chemical element or compound, which can conduct electricity under some conditions but not others, making it a good medium for the control of electrical current. Its conductance varies depending on the current or voltage applied to a control electrode, or on the intensity of irradiation by infrared (IR), visible light, ultraviolet (UV), or X rays.

The specific properties of a semiconductor depend on the impurities, or dopants, added to it. An N-type semiconductor carries current mainly in the form of negatively-charged electrons, in a manner similar to the conduction of current in a wire. A P-type semiconductor carries current predominantly as electron deficiencies called holes. A hole has a positive electric charge, equal and opposite to the charge on an electron. In a semiconductor material, the flow of holes occurs in a direction opposite to the flow of electrons.

Elemental semiconductors include antimony, arsenic, boron, carbon, germanium, selenium, silicon, sulfur, and tellurium. silicon is the best-known of these, forming the basis of most integrated circuits (ICs). Common semiconductor compounds include gallium arsenide, indium antimonide, and the oxides of most metals. Of these, gallium arsenide (GaAs) is widely used in low-noise, high-gain, weak-signal amplifying devices.

A semiconductor device can perform the function of a vacuum tube having hundreds of times its volume. A single integrated circuit (IC), such as a microprocessor chip, can do the work of a set of vacuum tubes that would fill a large building and require its own electric generating plant.

Conductivity of semiconductors

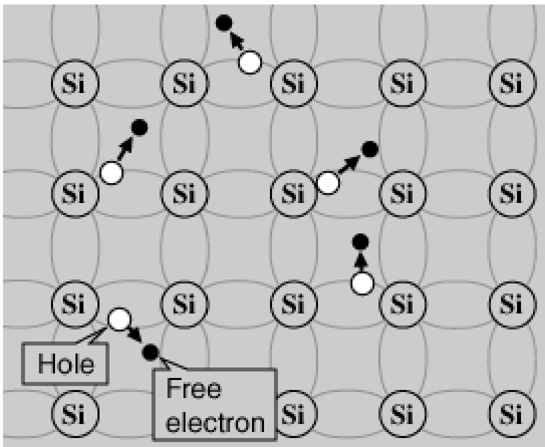
A semiconductor is very different from a conductor. In fact, a semiconductor is almost an insulator. The only difference between semiconductor and insulator is energy levels. An insulator requires a great deal of energy (maybe 10 eV) to break an electron free from an atom. A semiconductor requires only about 1 eV to free an electron. A conductor has some electrons free to move without any added energy.

When a semiconductor is extremely cold, almost all electrons are held tightly by individual atoms. It is hard to make them move through the material. When a semiconductor is heated, the heat energy knocks loose some of the electrons. These loose electrons can move through the material easily. The conductivity is higher. As more heat energy is added, more electrons break away from individual atoms, becoming free to move through the semiconductor. Higher temperature means greater conductivity. This is NOT true for conductors. Conductors already have plenty of loose electrons. Higher temperature tends to go into these loose electrons. Adding energy makes the loose electrons move in less organized patterns. It becomes more difficult to control the direction of the electrons. This makes the conductor have less conductivity when temperature is higher.

Intrinsic Semiconductor

A silicon crystal is different from an insulator because at any temperature above absolute zero temperature, there is a finite probability that an electron in the lattice will be knocked loose from its position, leaving behind an electron deficiency called a "hole".

If a voltage is applied, then both the electron and the hole can contribute to a small current flow.



The conductivity of a semiconductor can be modeled in terms of the band theory of solids. The band model of a semiconductor suggests that at ordinary temperatures there is a finite possibility that electrons can reach the conduction band and contribute to electrical conduction.

The term intrinsic here distinguishes between the properties of pure "intrinsic" silicon and the dramatically different properties of doped n-type or p-type semiconductors.

Extrinsic semiconductor

An extrinsic semiconductor is a semiconductor that has been *doped*, that is, into which a doping agent has been introduced, giving it different electrical properties than the intrinsic (pure) semiconductor. Doping involves adding dopant atoms to an intrinsic semiconductor, which changes the electron and hole carrier concentrations of the semiconductor at thermal equilibrium. Dominant carrier concentrations in an extrinsic semiconductor classify it as either an n-type or p-type semiconductor. The electrical properties of extrinsic semiconductors make them essential components of many electronic devices.

Semiconductor doping

Semiconductor doping is the process that changes an intrinsic semiconductor to an extrinsic semiconductor. During doping, impurity atoms are introduced to an intrinsic semiconductor. Impurity atoms are atoms of a different element than the atoms of the intrinsic semiconductor. Impurity atoms act as either donors or acceptors to the intrinsic semiconductor, changing the electron and hole concentrations of the semiconductor. Impurity atoms are classified as donor or acceptor atoms based on the effect they have on the intrinsic semiconductor. Donor impurity atoms have more valence electrons than the atoms they replace in the intrinsic semiconductor lattice. Donor impurities "donate" their extra valence electrons to a semiconductor's conduction band, providing excess electrons to the intrinsic semiconductor. Excess electrons increase the electron carrier concentration (n_0) of the semiconductor, making it n-type.

Acceptor impurity atoms have less valence electrons than the atoms they replace in the intrinsic semiconductor. They "accept" electrons from the semiconductor's valence band. This provides excess holes to the intrinsic semiconductor. Excess holes increase the hole carrier concentration (p_0) of the semiconductor, creating a p-type semiconductor.

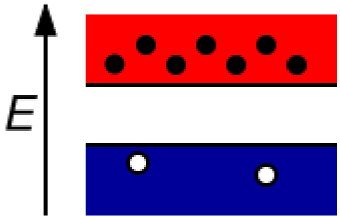
Semiconductors and dopant atoms are defined by the column of the periodic table of elements they fall in. The column definition of the semiconductor determines how many valence electrons its atoms have and whether dopant atoms act as the semiconductor's donors or acceptors. Group IV semiconductors use group V atoms as donors and group III atoms as acceptors.

Group III-V semiconductors use group VI atoms as donors and group II atoms as acceptors. Group III-V semiconductors can also use group IV atoms as either donors or acceptors. When a group IV atom replaces the group III element in the semiconductor lattice, the group IV atom acts as a donor. Conversely, when a group IV atom replaces the group V element, the group IV atom acts as an acceptor. Group IV atoms can act as both donors and acceptors; therefore, they are known as amphoteric impurities.

	Intrinsic semiconductor	**Donor atoms**	**Acceptor atoms**
Group IV semiconductors	Silicon, Germanium	Phosphorus, Arsenic	Boron, Aluminium
Group III-V semiconductors	Aluminum phosphide, Aluminum arsenide, Gallium arsenide	Selenium, Tellurium, Silicon, Germanium	Beryllium, Zinc, Cadmium, Silicon, Germanium

The two types of extrinsic semiconductor

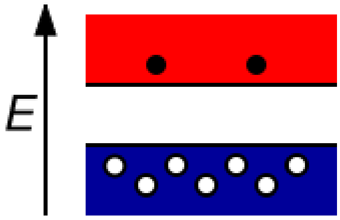
N-type semiconductors



Band structure of an n-type semiconductor. Dark circles in the conduction band are electrons and light circles in the valence band are holes. The image shows that the electrons are the majority charge carrier.

Extrinsic semiconductors with a larger electron concentration than hole concentration are known as n-type semiconductors. The phrase 'n-type' comes from the negative charge of the electron. In n-type semiconductors, electrons are the majority carriers and holes are the minority carriers. N-type semiconductors are created by doping an intrinsic semiconductor with donor impurities. In an n-type semiconductor, the Fermi energy level is greater than the that of the intrinsic semiconductor and lies closer to the conduction band than the valence band.

P-type semiconductors



Band structure of a p-type semiconductor. *Dark circles in the conduction band are electrons and light circles in the valence band are holes. The image shows that the holes are the majority charge carrier*

As opposed to n-type semiconductors, p-type semiconductors have a larger hole concentration than electron concentration. The phrase 'p-type' refers to the positive charge of the hole. In p-type semiconductors, holes are the majority carriers and electrons are the minority carriers. P-type semiconductors are created by doping an intrinsic semiconductor with acceptor impurities. P-type semiconductors have Fermi energy levels below the intrinsic Fermi energy level. The Fermi energy level lies closer to the valence band than the conduction band in a p-type semiconductor.

Utilization of extrinsic semiconductors

Extrinsic semiconductors are components of many common electrical devices. A semiconductor diode (devices that allow current flow in only one direction) consists of p-type and n-type semiconductors placed in junction with one another. Currently, most semiconductor diodes use doped silicon or germanium.

Transistors (devices that enable current switching) also make use of extrinsic semiconductors. Bipolar junction transistors (BJT) are one type of transistor. The most common BJTs are NPN and PNP type. NPN transistors have two layers of n-type semiconductors sandwiching a p-type semiconductor. PNP transistors have two layers of p-type semiconductors sandwiching an n-type semiconductor.

Field-effect transistors (FET) are another type of transistor implementing extrinsic semiconductors. As opposed to BJTs, they are unipolar and considered either N-channel or P-channel. FETs are broken into two families, junction gate FET (JFET) and insulated gate FET (IGFET).

Other devices implementing the extrinsic semiconductor:

Lasers ,Solar cells ,Photodetectors ,Light-emitting diodes,Thyristors

HALL EFFECT

Experiment that shows the sign of the charge carriers in a conductor. In 1879 E. H. Hall discovered that when he placed a metal strip carrying a current in a magnetic field, a voltage difference was produced across the strip. The side of the strip that is at the higher voltage depends on the sign of the charge carrier; Hall's work demonstrated that in metals the charge carriers are negative. Today it is known that this negative charge carrier is the electron. The Hall effect has again become an active area of research with the discovery of the quantized Hall effect, for which Klaus von Klitzing was awarded the 1985 Nobel Prize in physics. Before von Klitzing's work it was thought that the amount of voltage difference across the strip varied in direct proportion to the strength of the magnetic field—the greater the magnetic field, the greater the voltage difference. Von Klitzing showed that under the special conditions of low temperature, high magnetic field, and two-dimensional electronic systems (in which the electrons are confined to move in planes), the voltage difference increases as a series of steps with increasing magnetic field.

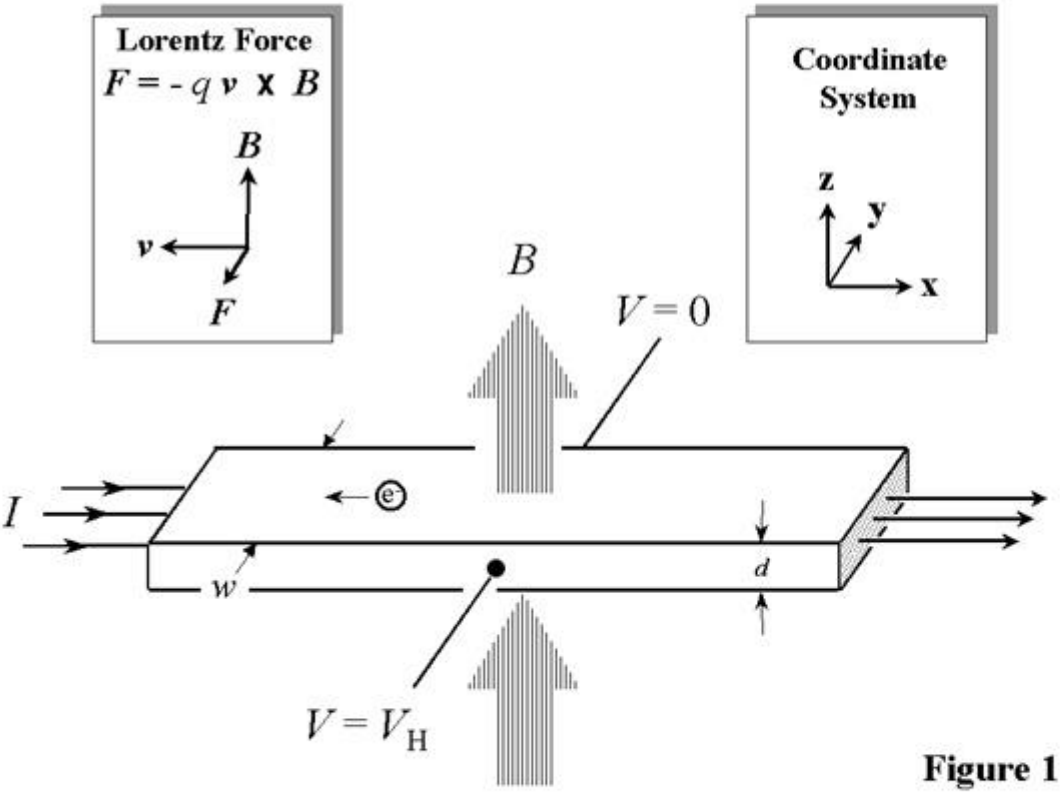


Figure 1

Schematic of the Hall effect in a long, thin bar of semiconductor with four ohmic contacts. The direction of the magnetic field B is along the z-axis and the sample has a finite thickness d.

DIELECTRICS

A dielectric is a nonconducting substance, i.e. an insulator. The term was coined by William Whewell in response to a request from Michael Faraday. Whewell considered "dia-electric", from the Greek "*dia*" meaning "through", since an electric field passes through the material but felt that "dielectric" was easier to pronounce. Although "dielectric" and "insulator" are generally considered synonymous, the term "dielectric" is more often used when considering the effect of alternating electric fields on the substance while "insulator" is more often used when the material is being used to withstand a high electric field. Von Hippel, in his seminal book takes this definition further. He states,

"*Dielectrics*... are not a narrow class of so-called insulators, but the broad expanse of *nonmetals* considered from the standpoint of their interaction with electric, magnetic, of electromagnetic fields. Thus we are concerned with gases as well as with liquids and solids, and with the storage of electric and magnetic energy as well as its dissipation."

Dielectrics is the study of dielectric materials and involves physical models to describe how an electric field behaves inside a material. It is characterized by how an electric field interacts with an atom and is therefore possible to approach from either a classical interpretation or a quantum one.

Many phenomena in electronics, solid state and optical physics can be described using the underlying assumptions of the dielectric model. This can mean that the same mathematical objects can go by many different names.

APPLICATIONS

Capacitors

Commercially manufactured capacitors typically use a solid dielectric material with high permittivity as the intervening medium between the stored positive and negative charges. This material is often referred to in technical contexts as the "capacitor dielectric" . The most obvious advantage to using such a dielectric material is that it prevents the conducting plates on which the charges are stored from coming into direct electrical contact. More significantly however, a high permittivity allows a greater charge to be stored at a given voltage.

Dielectric materials used for capacitors are also chosen such that they are resistant to ionization. This allows the capacitor to operate at higher voltages before the insulating dielectric ionizes and begins to allow undesirable current flow.

Cable insulation

The term "dielectric" may also refer to the insulation used in power and RF cables.

Some practical dielectrics

Dielectric materials can be solids, liquids, or gases. In addition, a high vacuum can also be a useful, lossless dielectric even though its relative dielectric constant is only unity.

Solid dielectrics are perhaps the most commonly used dielectrics in electrical engineering, and many solids are very good insulators. Some examples include porcelain, glass, and most plastics. Air, nitrogen and sulfur hexafluoride are the three most commonly used gaseous dielectrics.

- Industrial coatings such as parylene provide a dielectric barrier between the substrate and its environment.
- Mineral oil is used extensively inside electrical transformers as a fluid dielectric and to assist in cooling. Dielectric fluids with higher dielectric constants, such as electrical grade castor oil, are often used in high voltage capacitors to help prevent corona discharge and increase capacitance.
- Because dielectrics resist the flow of electricity, the surface of a dielectric may retain *stranded* excess electrical charges. This may occur accidentally when the dielectric is rubbed (the triboelectric effect). This can be useful, as in a Van de Graaff generator or electrophorus, or it can be potentially destructive as in the case of electrostatic discharge.
- Specially processed dielectrics, called electrets (also known as ferroelectrics), may retain excess internal charge or "frozen in" polarization. Electrets have a

semipermanent external electric field, and are the electrostatic equivalent to magnets. Electrets have numerous practical applications in the home and industry.

- Some dielectrics can generate a potential difference when subjected to mechanical stress, or change physical shape if an external voltage is applied across the material. This property is called piezoelectricity. Piezoelectric materials are another class of very useful dielectrics.
- Some ionic crystals and polymer dielectrics exhibit a spontaneous dipole moment which can be reversed by an externally applied electric field. This behavior is called the ferroelectric effect. These materials are analogous to the way ferromagnetic materials behave within an externally applied magnetic field. Ferroelectric materials often have very high dielectric constants, making them quite useful for capacitors.

CLAUSIUS–MOSSOTTI RELATION

The Clausius–Mossotti equation is named after the Italian physicist Ottaviano-Fabrizio Mossotti, whose 1850 book analyzed the relationship between the dielectric constants of two different media, and the German physicist Rudolf Clausius, who gave the formula explicitly in his 1879 book in the context not of dielectric constants but of indices of refraction. The same formula also arises in the context of conductivity, in which it is known as Maxwell's formula. It arises yet again in the context of refractivity, in which it is known as the Lorentz–Lorenz equation.

Clausius–Mossotti factor

The Clausius–Mossotti factor can be expressed in terms of complex permittivities:

$$K(\omega) = \frac{\epsilon_p^* - \epsilon_m^*}{\epsilon_p^* + 2\epsilon_m^*}$$

$$\epsilon^* = \epsilon + \frac{\sigma}{i\omega} = \epsilon - \frac{i\sigma}{\omega}$$

Where

ε is the permittivity

(where the subscript p refers to a lossless dielectric sphere suspended in a medium m)
σ is the conductivity
ω is the angular frequency of the applied electric field
i is the square root of -1

In the context of electro kinetic manipulation, the real part of the Clausius-Mossotti factor is a determining factor for the dielectrophoretic force on a particle, where as the imaginary part is a determining factor for the electro rotational torque on the particle. Other factors are, of course, the geometries of the particle to be manipulated and the electric field.

FERROELECTRIC CRYSTALS

Ferroelectricity is a physical property of a material whereby it exhibits a spontaneous electric polarization, the direction of which can be switched between equivalent states by the application of an external electric field. The experimental evidence for this domain switching is a hysteresis loop. The term is used in analogy to ferromagnetism, in which a material exhibits a permanent magnetic moment. Ferromagnetism was already known when ferroelectricity was discovered in 1920 in Rochelle salt by Valasek. Thus, the prefix "ferro", meaning iron, was used to describe the property despite the fact that most ferroelectric materials do not have iron in their lattice.

Ferroelectrics are key materials in microelectronics. Their excellent dielectric properties make them suitable for electronic components such as tunable capacitors and memory cells.

Applications

The nonlinear nature of ferroelectric materials can be used to make capacitors with tunable capacitance. Typically, a ferroelectric capacitor simply consists of a pair of electrodes sandwiching a layer of ferroelectric material. The permittivity of ferroelectrics is not only tunable but commonly also very high in absolute value, especially when close to the phase transition temperature. This fact makes ferroelectric capacitors small in size compared to dielectric (non-tunable) capacitors of similar capacitance.

The spontaneous polarization of ferroelectric materials implies a hysteresis effect which can be used as a memory function. Indeed, ferroelectric capacitors are used to make ferroelectric RAM for computers and RFID cards. These applications are usually based on thin films of ferroelectric materials as this allows the high coercive field required to switch the polarization to be achieved with a moderate voltage, though a side effect of this is that a great deal of attention needs to be paid to the interfaces, electrodes and sample quality for devices to work reliably.

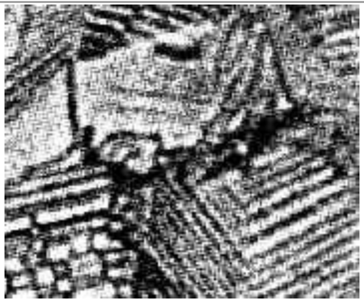
All ferroelectrics are required by symmetry considerations to be also piezoelectric and pyroelectric. The combined properties of memory, piezoelectricity, and pyroelectricity make ferroelectric capacitors very useful, e.g. for sensor applications. Ferroelectric capacitors are used in medical ultrasound machines (the capacitors generate and then listen for the ultrasound ping used to image the internal organs of a body), high quality infrared cameras (the infrared image is projected onto a two dimensional array of ferroelectric capacitors capable of detecting temperature differences as small as millionths of a degree Celsius), fire sensors, sonar, vibration sensors, and even fuel injectors on diesel engines. As well, the electro-optic modulators that form the backbone of the Internet are made with ferroelectric materials.

One new idea of recent interest is the *ferroelectric tunnel junction* (*FTJ*) in which a contact made up by nanometer-thick ferroelectric film placed between metal electrodes. The thickness of the ferroelectric layer is thin enough to allow tunneling of electrons. The piezoelectric and interface effects as well as the depolarization field may lead to a giant electroresistance (GER) switching effect.

Another hot topic is multiferroics, where researchers are looking for ways to couple magnetic and ferroelectric ordering within a material or heterostructure; there are several recent reviews on this topic.

FERROELECTRIC DOMAINS

Ferroelectric domains, sometimes known as Weiss domains, are areas of local dipole alignment - with an associated net dipole moment and net polarization.



Domains are separated from one another by 'domain walls'. These domain boundaries are usually described according to the angle between the domains that they separate. The most common found are 90° and 180° boundaries.

The picture above shows an area of a ferroelectric material clearly displaying a domain structure. The dark lines are 90° domain walls.

The domain structure and behaviour of a material will critically affect its operational performance

Most importantly, the domain wall mobility will affect the high frequency performance of the material when used as an actuator.

In the presence of an applied electric field, domains that are aligned with the direction of the field will grow at the expense of the less well aligned domains. This may be visualized in terms of the boundary between the domains moving.

Several synthesis and processing techniques may be adopted to control the mobility of the domain wall and hence reduce losses.

The domain structure can also change over time by a process known as ageing. This causes degradation to the dielectric properties and often causes device failure due to loss of insulation resistance.

If high frequency operation is required with very low losses and no domain ageing then electrostrictive materials may offer a solution. Electrostrictive ceramics possess no spontaneous polarization and no domain structure. Examples of such materials are lead magnesium niobate titanate (PMNT) and various lead lanthanum zirconate titanate (PLZT) compositions

POSSIBLE QUESTIONS

PART-B (10 Marks)

1. Define Hall Effect. Explain the dielectric materials with significance properties.
2. Define the reciprocal lattice. Explain the various properties of reciprocal lattice
3. Describe about the Clausius –Mossoti equation.
4. Describe in detail about interplanar spacing for SC, FCC, BCC.
5. Describe the Bragg condition in terms of reciprocal lattice and explain NaCl structure
6. Describe the neutron scattering and explain how it is different from X-ray diffraction.
7. Describe the rotatory crystal method of X-ray diffraction.
8. What is mean by Hall effect? Explain briefly the physical origin and uses of Hall effect.
9. What is Dielectric? Explain Clausius – Mossoti equation.
10. Explain the vibrations of one dimensional diatomic lattice

KARPAGAM ACADEMY OF HIGHER EDUCATION,COIMBATORE-21

DEPARTMENT OF PHYSICS

CLASS: I M.Sc., PHYSICS (2019-2021)

PART – A Online Examination (1 mark questions)
SUBJECT: CONDENSED MATTER PHYSICS
SUBJECT CODE: 19PHP101

UNIT - I

Questions	Option-1	Option-2	Option-3	Option-4	Key
The number of atoms present in the unit cell of HCP structure is	2	4	6	7	6
Which of the following elements is a covalently bonded crystal?	aluminium	sodium chloride	germanium	lead	germanium
The forbidden energy gap of carbon in diamond structure is	7.0 eV	1.0 eV	0.01 eV	none	7.0 eV
For silicon doped with trivalent impurity,	ne >> nh	ne > nh	nh >> ne	nh > ne	nh >> ne
Metallic bond is not characterized by	ductility	high conductivity.	directionality	opacity	directionality
If the Fermi energy of silver at 0 K is 5 electron volt, the mean energy of electron in silver at 0 K is	6 electron volt.	12 electron volt.	1.5 electron volt.	3 electron volt.	3 electron volt.
The Fermi level in an n-type semiconductor at 0 K lies	below the donor level.	Half way between the bottom of conduction band and donor level.	Exactly in the middle of hand gap.	Half way between the top of valence band and the acceptor level.	Half way between the bottom of conduction band and donor level.
Piezoelectric effect is the production of electricity by	chemical effect.	pressure	varying magnetic field	temperature	pressure
Electromigration in metallization refers to the diffusion (under the influence of current) of	Al	Cu in A1-Cu alloy.	Si	Na	Al
Fine grain sizes are obtained by	slow cooling.	increasing nucleation rate	decreasing growth rate	fast cooling	slow cooling
Zinc has hcp structure. In a unit cell of zinc, the zinc	74% of volume of	80% of volume of	68% of volume of	90% of volume of	74% of volume of unit cell.

atoms occupy	unit cell.	unit cell.	unit cell.	unit cell.	
The density of carriers in a pure semiconductor is proportional to	exp(− Eg / kT)	exp(− 2Eg / kT)	exp(− 2Eg / kT2)	exp(− Eg / 2kT)	exp(− Eg / kT)
The probability of occupation of an energy level E, when E – EF = kT, is given by	0.73	0.63	0.5	0.27	0.27
majority charge carriers in p-type semiconductor are	ions	holes	free electrons.	conduction electrons.	holes
Polarization in a dielectric on application of electric field is	Displacement/separation of opposite charge centres.	Passing of current through dielectric.	Breaking of insulation.	Excitation of electrons to higher energy level.	Displacement/separation of opposite charge centres.
The radius of first Bohr orbit in the hydrogen atom is about	0.053 Å	0.530 Å	5.31 Å	53.10 Å	0.530 Å
The Fermi level is	an average value of all available energy levels.	an energy level at the top of the valence band.	the highest occupied energy level at 0 0C.	the highest occupied energy level at 0 K.	the highest occupied energy level at 0 K.
Among the common dielectric materials, the highest dielectric strength is possessed by	mica.	polyethylene.	PVC	transformer oil.	mica.
In intrinsic semiconductor there are	no mobile holes.	no free electrons.	as many free electrons as there are holes.	neither free electrons nor mobile holes.	as many free electrons as there are holes.
Mobility of electron is	Average flow of electrons per unit field.	Average applied field per unit drift velocity.	Average drift velocity per unit field.	Reciprocal of conductivity per unit charge.	Average drift velocity per unit field.
In a dielectric, the power loss is proportional to	ω	ω ˆ2	1/ω	1/ω2	ω
Above curie temperature, the spontaneous polarization for ferro electric materials is	zero	1	half	infinity	zero
Fermi level represents the	0 %.	25 %.	50 %.	100 %.	50 %.

energy level with probability of its occupation of					
The acceptor type impurity is formed by adding impurity of valency	6	5	4	3	3
If the atomic number of an element is Z, and its atomic mass number is A, the number of protons in its nucleus is	A	Z	A-Z	A/Z	Z
Miller indices of the diagonal plane of a cube are	2,0,0	1,1,1	0,1,0	1,1,0	1,1,0
Highest electrical resistivity exists in	platinum wire.	nichrome wire.	silver wire.	kanthal wire.	nichrome wire.
Hall effect can be used to measure	mobility of semiconductors.	conductivity of semiconductors.	resistivity of semiconductors.	all of these.	all of these.
The unit of dielectric constant is	Dimensionless	Fm−1	CV−1	Fc−1	Fm−1
Pure silicon at zero K is an	intrinsic semiconductor.	extrinsic semiconductor.	metal.	insulator.	insulator.
The dielectric strength of a material is the highest	current which can pass through it.	voltage that can be applied to it.	field (voltage per meter thickness) that can be with-stood by it.	current density that can be transmitted by it.	field (voltage per meter thickness) that can be with-stood by it.
A Ge atom contains	four protons	four valence electrons	six valence electrons	only two electron orbits	four valence electrons
The energy required to break a covalent bond in a semiconductor	is equal to 1 eV	is equal to the width of the forbidden gap	is greater in Ge than in Si	is the same in Ge and Si	is equal to the width of the forbidden gap
An electron in the conduction band	is located near the top of the crystal	has no charge	has a higher energy than an electron in the valence band	is bound to its parent atom	has a higher energy than an electron in the valence band

At 0° K, all the valence electrons in an intrinsic semiconductor	are in the valence band	are in the forbidden gap	are in the conduction band	are free electrons	are in the valence band
Insulating material used in spark plug is	rubber	porcelain	mica	Polysterene	porcelain
Which of the following has piezoelectric properties:	corundum	neoprene	quartz	glass	quartz
For metallization, the property not desirable is	reproducibility	quick dissipation of heat	low thermal conductivity	high melting point	reproducibility
The correct order of the co-ordination number in simple cubic, body centered cubic and face centered cubic of unit cell is	6, 8, 12.	8, 12, 12.	12, 8, 12.	6, 8, 8.	6, 8, 12.
At absolute zero temperature, the probability of finding an electron at an energy level E is zero when	E < EF	E > Ef	E =Ef/2	None	E > Ef
In an intrinsic semiconductor, there are	no mobile holes.	no free electrons.	neither free electrons nor mobile holes.	equal number of free electrons and mobile holes.	equal number of free electrons and mobile holes.
The probability of occupancy of electrons above Fermi level at T=0°K is	0 %.	25%.	50%.	100%.	0 %.
In a ferroelectric material, the spontaneous polarization vanishes above	Transition temperature.	Debye temperature.	Fermi temperature.	Curie temperature.	Curie temperature.
P-type and N-type extrinsic semiconductors are formed by adding impurities of valency	5 and 3 respectively.	5 and 4 respectively.	3 and 5 respectively.	3 and 4 respectively.	3 and 5 respectively.
Which one is a secondary form of energy?	Furnace oil	natural gas	electricity	coal	electricity
In an intrinsic semiconductor, the Fermi level	Lies at the center of forbidden energy gap.	Is near the conduction band.	Is near the valence band.	May be anywhere in the forbidden energy	Lies at the center of forbidden energy gap.

				gap.	
Most commonly used semiconductor material is	Silicon	Germanium	Mixture of silicon and germanium	None of the above.	Silicon
At room temperature a semiconductor material is	Perfect insulator	Conductor	Slightly conducting	Any one of the above.	Slightly conducting
The process of adding impurities to a pure semiconductor is called	Mixing	Doping	Diffusing	None of the above	Doping
Impurities like boron, aluminum, gallium or indium are added to intrinsic semiconductor to form	N-type doped semiconductor	P-type doped semiconductor	A junction diode	All of these	P-type doped semiconductor
In a N-type semiconductor, the position of Fermi-level	Is lower than the center of energy gap	Is at the center of energy gap	Is higher than the center of energy gap	Can be any where	Is higher than the center of energy gap
In a metal	The electrical conduction is by electrons and holes	The conductivity decreases with the rise in temperature	The conduction band is empty	None of the above	The conductivity decreases with the rise in temperature
The energy gap in a semiconductor	Increases with temperature	Does not change with temperature	Decreases with temperature	Is zero	Decreases with temperature
In a single-component condensed system, if degree of freedom is zero, maximum number of phases that can co-exist	0	1	2	3	2
Impurity not responsible for temper embrittlement	Sn	Sb	Si	As	Si
Miller indices for Octahedral plane in cubic crystal	1,0,0	1,1,0	1,1,1	none	1,1,1
Repeatable entity of a crystal structure is known as	Crystal	Lattice	Unit cell	Miller indices	Unit cell
Coordination number for closest packed crystal	16	12	8	4	12

structure					
Coordination number in simple cubic crystal structure	1	2	3	4	2
The atomic diameter of an BCC crystal (if a is lattice parameter) is	a	a/2	a/(4√3)	a/(4√2)	a/(4√3)
Which of the following is not the characteristic of ionic solids?	Very low value of electrical conductivity in the molten state.	Brittle nature.	Very strong forces of interactions.	Anisotropic nature.	Very low value of electrical conductivity in the molten state.
Graphite is a good conductor of electricity due to the presence of ___________.	lone pair of electrons	free valence electrons	cations	anions	free valence electrons
Electrical conductivity of insulators is the range ______________.	10-10(Ω-mm)-1	10-10(Ω-cm)-1	10-10(Ω-m)-1	10-8(Ω-m)-1	10-10(Ω-mm)-1
Units for electric field strength	A/cm2	mho/meter	cm2/V.s	V/cm	cm2/V.s
Energy band gap size for semiconductors is in the range ________ eV.	1 to 2	2 to 3	3 to 4	> 4	2 to 3
Energy band gap size for insulators is in the range ________ eV.	1 to 2	2 to 3	3 to 4	> 4	3 to 4
Flow of electrons is affected by the following	Thermal vibrations	Impurity atoms	Crystal defects	all	all
Not a super conductive metallic element	Fe	Al	Ti	W	Al
Fermi energy level for intrinsic semiconductors lies	At middle of the band gap	Close to conduction band	Close to valence band	None	Close to valence band
Fermi energy level for p-type extrinsic semiconductors lies	At middle of the band gap	Close to conduction band	Close to valence band	None	Close to conduction band
Fermi energy level for n-type extrinsic semiconductors lies	At middle of the band gap	Close to conduction band	Close to valence band	None	Close to conduction band
Not an example for intrinsic semiconductor	Silicon	Al	germanium	Sn	Silicon
In intrinsic semiconductors, number of electrons ___________	Equal	Greater than	Less than	Can not define	Less than

number of holes.					
In n-type semiconductors, number of holes ___________ number of electrons.	Equal	Greater than	Less than	Can not define	Can not define
In p-type semiconductors, number of holes ___________ number of electrons.	Equal	Greater than	Less than	Can not define	Equal
Mobility of holes is ____________ mobility of electrons in intrinsic semiconductors.	Equal	Greater than	Less than	Can not define	Can not define
Fermi level for extrinsic semiconductor depends on	Donor element	Impurity concentration	Temperature	All	All
Value of dielectric constant for a material ___________.	Equal to 1	Greater than 1	Less than 1	Zero.	Equal to 1
High dielectric constant material is must for ___________.	Insulation of wires	Generators	Switch bases	Generators.	Insulation of wires
Example for ferro-electric material	Potassium niobate	Lead titanate	Lead zirconate	quartz	Lead titanate
In a ferroelectric material, the spontaneous polarization vanishes above	Transition temperature.	Debye temperature.	Fermi temperature.	Curie temperature.	Curie temperature.
P-type and N-type extrinsic semiconductors are formed by adding impurities of valency	5 and 3 respectively.	5 and 4 respectively.	3 and 5 respectively.	3 and 4 respectively.	3 and 5 respectively.
Which one is a secondary form of energy?	Furnace oil	natural gas	electricity	coal	electricity
In an intrinsic semiconductor, the Fermi level	Lies at the center of forbidden energy gap.	Is near the conduction band.	Is near the valence band.	May be anywhere in the forbidden energy gap.	Lies at the center of forbidden energy gap.
Most commonly used semiconductor material is	Silicon	Germanium	Mixture of silicon and germanium	None of the above.	Silicon
At room temperature a semiconductor material is	Perfect insulator	Conductor	Slightly conducting	Any one of the above.	Slightly conducting
The process of adding impurities to a pure	Mixing	Doping	Diffusing	None of the above	Doping

semiconductor is called					
Impurities like boron, aluminum, gallium or indium are added to intrinsic semiconductor to form	N-type doped semiconductor	P-type doped semiconductor	A junction diode	All of these	P-type doped semiconductor
In a N-type semiconductor, the position of Fermi-level	Is lower than the center of energy gap	Is at the center of energy gap	Is higher than the center of energy gap	Can be any where	Is higher than the center of energy gap
In a metal	The electrical conduction is by electrons and holes	The conductivity decreases with the rise in temperature	The conduction band is empty	None of the above	The conductivity decreases with the rise in temperature
The energy gap in a semiconductor	Increases with temperature	Does not change with temperature	Decreases with temperature	Is zero	Decreases with temperature
In a single-component condensed system, if degree of freedom is zero, maximum number of phases that can co-exist	0	1	2	3	2
Impurity not responsible for temper embrittlement	Sn	Sb	Si	As	Si
Miller indices for Octahedral plane in cubic crystal	1,0,0	1,1,0	1,1,1	none	1,1,1
Repeatable entity of a crystal structure is known as	Crystal	Lattice	Unit cell	Miller indices	Unit cell
Coordination number for closest packed crystal structure	16	12	8	4	12
Coordination number in simple cubic crystal structure	1	2	3	4	2
The atomic diameter of an BCC crystal (if a is lattice parameter) is	a	a/2	$a/(4\sqrt{3})$	$a/(4\sqrt{2})$	$a/(4\sqrt{3})$
Which of the following is	Very low	Brittle	Very strong	Anisotropic	Very low value

not the characteristic of ionic solids?	value of electrical conductivity in the molten state.	nature.	forces of interactions.	nature.	of electrical conductivity in the molten state.
Graphite is a good conductor of electricity due to the presence of ___________.	lone pair of electrons	free valence electrons	cations	anions	free valence electrons
Electrical conductivity of insulators is the range ______________.	10-10(Ω-mm)-1	10-10(Ω-cm)-1	10-10(Ω-m)-1	10-8(Ω-m)-1	10-10(Ω-mm)-1
Units for electric field strength	A/cm2	mho/meter	cm2/V.s	V/cm	cm2/V.s
Energy band gap size for semiconductors is in the range _________ eV.	1 to 2	2 to 3	3 to 4	> 4	2 to 3
Energy band gap size for insulators is in the range _________ eV.	1 to 2	2 to 3	3 to 4	> 4	3 to 4
Flow of electrons is affected by the following	Thermal vibrations	Impurity atoms	Crystal defects	all	all
Not a super conductive metallic element	Fe	Al	Ti	W	Al
Fermi energy level for intrinsic semiconductors lies	At middle of the band gap	Close to conduction band	Close to valence band	None	Close to valence band
Fermi energy level for p-type extrinsic semiconductors lies	At middle of the band gap	Close to conduction band	Close to valence band	None	Close to conduction band
Fermi energy level for n-type extrinsic semiconductors lies	At middle of the band gap	Close to conduction band	Close to valence band	None	Close to conduction band
Not an example for intrinsic semiconductor	Silicon	Al	germanium	Sn	Silicon
In intrinsic semiconductors, number of electrons ___________ number of holes.	Equal	Greater than	Less than	Can not define	Less than
In n-type semiconductors, number of holes ___________ number of electrons.	Equal	Greater than	Less than	Can not define	Can not define
In p-type semiconductors, number of holes ___________ number of	Equal	Greater than	Less than	Can not define	Equal

electrons.					
Mobility of holes is ____________ mobility of electrons in intrinsic semiconductors.	Equal	Greater than	Less than	Can not define	Can not define
Fermi level for extrinsic semiconductor depends on	Donor element	Impurity concentration	Temperature	All	All
Value of dielectric constant for a material ___________.	Equal to 1	Greater than 1	Less than 1	Zero.	Equal to 1
High dielectric constant material is must for ___________.	Insulation of wires	Generators	Switch bases	Generators.	Insulation of wires
Example for ferro-electric material	Potassium niobate	Lead titanate	Lead zirconate	quartz	Lead titanate

UNIT-II
SYLLABUS

Theory of Semiconductors Intrinsic and extrinsic semiconductors - Free carrier concentration in semiconductors – Fermi level and carrier concentration in semiconductors – Mobility of charge carriers – Effect of temperature on mobility – electrical conductivity of semiconductors – Hall Effect in semiconductors

INTRINSIC SEMICONDUCTORS

The semiconductor is divided into two types. One is Intrinsic Semiconductor and other is an Extrinsic semiconductor. The pure form of the semiconductor is known as the intrinsic semiconductor and the semiconductor in which intentionally impurities is added for making it conductive is known as the extrinsic semiconductor.The conductivity of the intrinsic semiconductor become zero at room temperature while the extrinsic semiconductor is very little conductive at room temperature. The detailed explanation of the two types of the semiconductor.

An extremely pure semiconductor is called as Intrinsic Semiconductor. On the basis of the energy band phenomenon, Its valence band is completely filled and the conduction band is completely empty. When the temperature is raised and some heat energy is supplied to it, some of the valence electrons are lifted to conduction band leaving behind holes in the valence band

The electrons reaching at the conduction band move randomly. The holes created in the crystal also free to move anywhere. This behavior of the semiconductor shows that they have a negative temperature coefficient of resistance. This means that with the increase in temperature, the resistivity of the material decreases and the conductivity increases.

EXTRINSIC SEMICONDUCTORS

A semiconductor to which an impurity at controlled rate is added to make it conductive is known as an extrinsic Semiconductor.
An intrinsic semiconductor is capable to conduct a little current even at room temperature, but it is not useful for the preparation of various electronic devices. Thus, to make it conductive a small amount of suitable impurity is added to the material.

Doping

The process by which an impurity is added to a semiconductor is known as Doping. The amount and type of impurity which is to be added to a material has to be closely controlled during the preparation of extrinsic semiconductor. Generally, one impurity atom is added to a 10^8 atoms of a semiconductor.

The purpose of adding impurity in the semiconductor crystal is to increase the number of free electrons or holes to make it conductive. If a Pentavalent impurity, having five valence electrons is added to a pure semiconductor a large number of free electrons will exist.

If a trivalent impurity having three valence electrons is added, a large number of holes will exist in the semiconductor.

Depending upon the type of impurity added the extrinsic semiconductor may be classified as **n type semiconductor** and **p type semiconductor**.

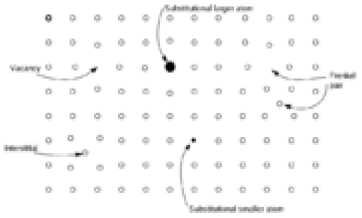
CLASSIFICATION OF DEFECTS

POINT DEFECT

Point defects are defects which are not extended in space in any dimension. There is not strict limit for how small a "point" defect should be, but typically the term is used to mean defects which involve at most a few extra or missing atoms without an ordered structure of the defective positions. Larger defects in an ordered structure are usually considered dislocation loops. For historical reasons, many point defects especially in ionic crystals are called 'centers': for example the vacancy in many ionic solids is called an F-center.

Vacancies are sites which are usually occupied by an atom but which are unoccupied. If a neighboring atom moves to occupy the vacant site, the vacancy moves in the opposite direction to the site which used to be occupied by the moving atom. The stability of the surrounding crystal structure guarantees that the neighboring atoms will not simply collapse around the vacancy. In some materials, neighboring atoms actually move away from a vacancy, because they can better form bonds with atoms in the other directions. A vacancy (or pair of vacancies in an ionic solid) is sometimes called a Schottky defect.

Interstitials are atoms which occupy a site in the crystal structure at which there is usually not an atom. They are generally high energy configurations. Small atoms in some crystals can occupy interstices without high energy, such as hydrogen in palladium.



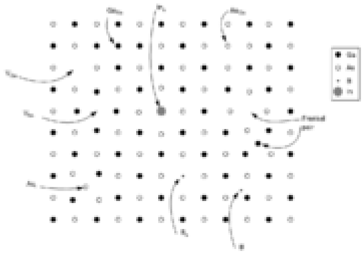
Schematic illustration of some simple point defect types in a monatomic solid

A nearby pair of a vacancy and an interstitial is often called a Frenkel defect or Frenkel pair

Impurities occur because materials are never 100% pure. In the case of an impurity, the atom is often incorporated at a regular atomic site in the crystal structure. This is neither a vacant site nor is the atom on an interstitial site and it is called a *substitutional* defect. The atom is not supposed to be anywhere in the crystal, and is thus an impurity.

Anti-site defects occur in an ordered alloy. For example, some alloys have a regular structure in which every other atom is a different species, for illustration assume that type A atoms sit on the cube corners of a cubic lattice, and type B atoms sit in center of the cubes. If one cube has an A atom at its center, the atom is on a site usually occupied by an atom, but it is not the correct type. This is neither a vacancy nor an interstitial, nor an impurity.

Topological defects are regions in a crystal where the normal chemical bonding environment is topologically different from the surroundings. For instance, in a perfect sheet of graphite (graphene) all atoms are in rings containing six atoms. If the sheet contains regions where the number of atoms in a ring is different from six, while the total number of atoms remains the same, a topological defect has formed. An example is the Stone Wales defect in nanotubes, which consists of two adjacent 5-membered and two 7-membered atom rings.



Schematic illustration of defects in a compound solid, using GaAs as an example.

Also amorphous solids may contain defects. These are naturally somewhat hard to define, but sometimes their nature can be quite easily understood. For instance, in ideally bonded amorphous silica all Si atoms have 4 bonds to O atoms and all O atoms have 2 bonds to Si atom. Thus e.g. an O atom with only one Si bond can be considered a defect in silica.

Complexes can form between different kinds of point defects. For example, if a vacancy encounters an impurity, the two may bind together if the impurity is too large for the lattice. Interstitials can form 'split interstitial' or 'dumbbell' structures where two atoms effectively share an atomic site, resulting in neither atom actually occupying the site.

THE SCHOTTKY DEFECT

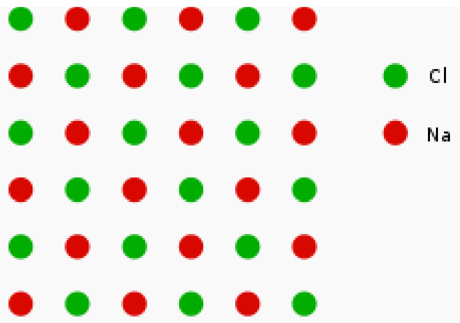
A Schottky defect is a type of point defect in a crystal lattice named after Walter H. Schottky.

The defect forms when oppositely charged ions leave their lattice sites, creating vacancies. These vacancies are formed in stoichiometric units, to maintain an overall neutral charge in the ionic solid. The vacancies are then free to move about as their own entities. Normally these defects will lead to a decrease in the density of the crystal. The following are the chemical equations in Kröger-Vink Notation for the formation of Schottky defects in TiO_2 and $BaTiO_3$.

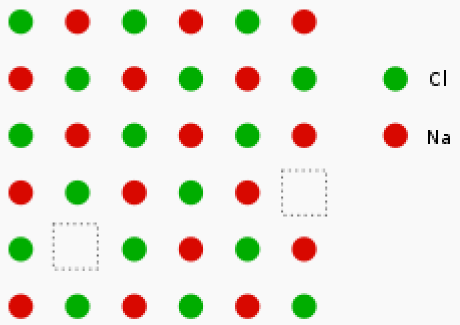
$$\emptyset \Leftrightarrow V_{Ti}'''' + 2V_O^{\bullet\bullet}$$

$$\emptyset \Leftrightarrow V_{Ba}'' + V_{Ti}'''' + 3V_O^{\bullet\bullet}$$

This can be illustrated schematically with a two-dimensional diagram of a sodium chloride crystal lattice:



The defect-free NaCl structure



Schottky defects within the NaCl structure

Definition

If in an ionic crystal of type A^+B^- an equal number of cations and anions are missing from their lattice sites so that electrical neutrality as well as stoichiometry is maintained this is called a Schottky Defect.

It is a vacancy defect (due to missing ions) and also a stoichiometric defect, as the ratio of the number of cations and anions remains the same.

Examples

This type of defect is shown in compounds with:

- highly ionic compounds
- high co-ordination number
- small difference in sizes of cations and anions

Examples : NaCl, KCl, CsCl, KBr, AgCl. etc.

Experimental observations show that at room temperature in an NaCl crystal there is one Schottky defect per 10^{16} ions.

FRENKEL DEFECT

The Frenkel Defect is shown by ionic solids. The smaller ion (usually the cation) is displaced from its lattice position to an interstitial site. It creates a *vacancy defect* at its original site and an *interstitial defect* at its new location.

Definition

A Frenkel defect, Frenkel point defect in a crystal lattice. The defect forms when an atom or cation leaves its place in the lattice, creating avacancy, and becomes an interstitial by lodging in a nearby location not usually occupied by an atom. Frenkel defects occur due to thermal vibrations, and it is theorized that there will be no defects in a crystal at 0 K. The phenomenon is named after the Soviet physicist Yakov Frenkel, who discovered it in 1926.

Examples

It is shown in ionic solids with large size difference between the anion and cation (with the cation usually smaller due to an increased effective nuclear charge) Some solids which display this defect - ZnS, AgCl, AgBr, AgI (due to the comparatively smaller size of Zn^{2+} and Ag^{+} ions)

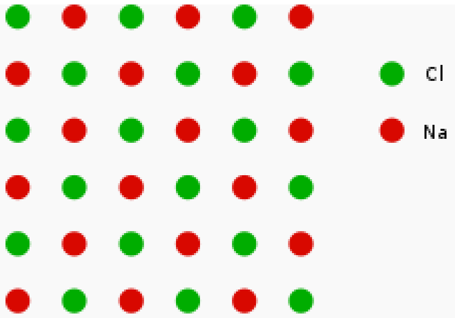
To be noted : AgBr shows both Frenkel as well as Schottky defects.

For example, consider a lattice formed by X and M ions. Suppose an M ion leaves the M sublattice, leaving the X sublattice unchanged. The number of interstitials formed will equal the number of vacancies formed.

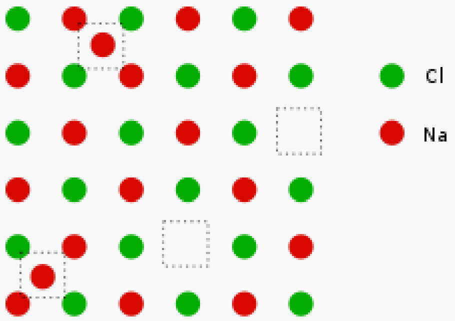
One form of a Frenkel defect reaction in MgO with the oxygen ion leaving the lattice and going into the interstitial site written in Kröger–Vink notation:

$$Mg_{Mg}^{\times} + O_{O}^{\times} \rightarrow O_{i}^{''} + V_{O}^{\bullet\bullet} + Mg_{Mg}^{\times}$$

This can be illustrated with the example of the sodium chloride crystal structure. The diagrams below are schematic two-dimensional representations.



The defect-free NaCl structure



Two Frenkel defects within the NaCl structure

F-CENTER

An F-Center or Farbe (German for color) center is a type of crystallographic defect in which an anionic vacancy in a crystal is filled by one or more electrons, depending on the charge of the missing ion in the crystal. Electrons in such a vacancy tend to absorb light in the visible spectrum such that a material that is usually transparent becomes colored. Thus the origin of the name, F-center, which originates from the German *Farbzentrum*. The translation of this term also provides the synonym color center, which can also refer to such defects. F-centers are often paramagnetic and can then be studied by electron paramagnetic resonance techniques. The greater the number of F-centers, the more intense is the color of the compound. A way of producing F centers is to heat a crystal in the presence of an atmosphere of the metal that constitutes the material, e.g.: NaCl heated in a metallic Na atmosphere.

$$Na^0 \rightarrow Na^+ + e^-$$

Na^+ is incorporated at NaCl crystal.
Cl^- vacancies are generated, because of the excess of Na^+.

These vacancies capture available e^-, neutralizing and forming F-centers; that is, the electrons released in this process diffuse to occupy the vacant places. Also, ionizing radiation can produce F-centers.

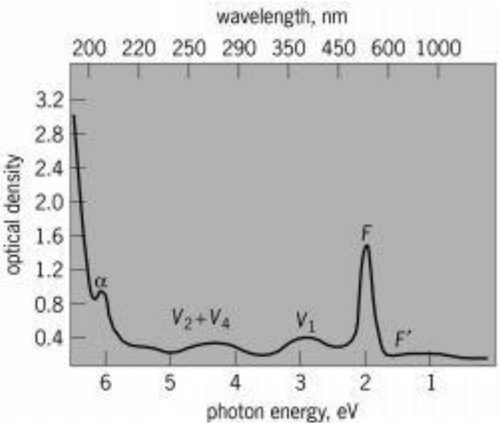
An H-center (a halogen interstitial) is in a sense the opposite, and hence a F-center and a H-center can combine and clear the lattice of a defect. This process can be photo induced, e.g. by a laser.

OTHER COLOUR CENTERS

Atomic and electronic defects of various types which produce optical absorption bands in otherwise transparent crystals such as the alkali halides, alkaline earth fluorides, or metal oxides. They are general phenomena found in a wide range of materials. Color centers are produced by gamma radiation or x-radiation, by addition of impurities or excess constituents, and sometimes through electrolysis. A well-known example is that of the *F*-center in alkali halides such as sodium chloride, NaCl. The designation *F*-center comes from the German word *Farbe*, which means color. *F*-centers in NaCl produce a band of optical absorption toward the blue end of the visible spectrum; thus the colored crystal appears yellow under transmitted light. On the other hand, KCl with *F*-centers appears magenta, and KBr appears blue.

Color centers have been under investigation for many years. Theoretical studies guided by detailed experimental work have yielded a deep understanding of specific centers. The crystals in which color centers appear tend to be transparent to light and to microwaves. Consequently, experiments which can be carried out include optical spectroscopy, luminescence and Raman scattering, magnetic circular dichroism, magnetic resonance, and electromodulation. Color centers find practical application in radiation dosimeters; schemes have been proposed to use color centers in high-density memory devices; and tunable lasers have been made from crystals containing color centers.

The illustration shows the absorption bands due to color centers produced in potassium bromide by exposure of the crystal at the temperature of liquid nitrogen (81 K) to intense penetrating x-rays. Several prominent bands appear as a result of the irradiation. The *F*-band appears at 600 nanometers and the so-called *V*-bands appear in the ultraviolet.



Absorption bands produced in a KBr crystal by exposure to x-rays at 81 K

Color bands such as the *F*-band and the *V*-band arise because of light absorption at defects dispersed throughout the lattice. This absorption is caused by electronic transitions at the centers. On the other hand, colloidal particles, each consisting of many atoms, dispersed through an optical medium also produce color bands. In this case, if the particles are large enough, the extinction of light is due to both light scattering and light absorption. Colloidal gold is responsible for the color of some types of ruby glass. Colloids may also form in alkali halide crystals—for example, during heat treatment of an additively colored crystal with an excess of alkali metal.

Atomically dispersed centers such as *F*-centers are part of the general phenomena of trapped electrons and holes in solids. The accepted model of the *F*-center is an electron trapped at a negative ion vacancy. Many other combinations of electrons, holes, and clusters of lattice vacancies have been used to explain the various absorption bands in ionic crystals.

Impurities can play an important role in color-center phenomena. Certain impurities in ionic crystals produce color bands characteristic of the foreign ion. For example, hydrogen can be incorporated into the alkali halides with resultant appearance of an absorption band (the *U*-band) in the ultraviolet. In this case, the *U*-centers interact with other defects. The rate at which *F*-centers are produced by x-irradiation is greatly increased by the incorporation of hydrogen, the *U*-centers being converted into *F*-centers with high efficiency.

DISLOCATIONS - SLIP AND PLASTIC DEFORMATION

Until the 1930s, one of the enduring challenges of materials science was to explain plasticity in microscopic terms. A naive attempt to calculate the shear stress at which neighbouring atomic planes *slip* over each other in a perfect crystal suggests that, for a material with shear modulus *G*, shear strength τ_m is given approximately by:

$$\tau_m = \frac{G}{2\pi}.$$

As shear modulus in metals is typically within the range 20 000 to 150 000 MPa, this is difficult to reconcile with shear stresses in the range 0.5 to 10 MPa observed to produce plastic deformation in experiments.

In 1934, Egon Orowan, Michael Polanyi and G. I. Taylor, roughly simultaneously, realized that plastic deformation could be explained in terms of the theory of dislocations. Dislocations can move if the atoms from one of the surrounding planes break their bonds and rebond with the atoms at the terminating edge. In effect, a half plane of atoms is moved in response to shear stress by breaking and reforming a line of bonds, one (or a few) at a time. The energy required to break a single bond is far less than that required to break all the bonds on an entire plane of atoms at once. Even this simple model of the force required to move a dislocation shows that plasticity is possible at much lower stresses than in a perfect crystal. In many materials, particularly ductile materials, dislocations are the "carrier" of plastic deformation, and the energy required to move them is less than the energy required to fracture the material. Dislocations give rise to the characteristic malleability of metals.

When metals are subjected to "cold working" (deformation at temperatures which are relatively low as compared to the material's absolute melting temperature, T_m, i.e., typically less than 0.3 T_m) the dislocation density increases due to the formation of new dislocations and dislocation multiplication. The consequent increasing overlap between the strain fields of adjacent dislocations gradually increases the resistance to further dislocation motion. This causes a hardening of the metal as deformation progresses. This effect is known as strain hardening (also “work hardening”). Tangles of dislocations are found at the early stage of deformation and appear as non well-defined boundaries; the process of dynamic recovery leads eventually to the formation of a cellular structure containing boundaries with misorientation lower than 15° (low angle grain boundaries). In addition, adding pinning points that inhibit the motion of dislocations, such as alloying elements, can introduce stress fields that ultimately strengthen the material by requiring a higher applied stress to overcome the pinning stress and continue dislocation motion.

The effects of strain hardening by accumulation of dislocations and the grain structure formed at high strain can be removed by appropriate heat treatment (annealing) which promotes the recovery and subsequent recrystallisation of the material.

The combined processing techniques of work hardening and annealing allow for control over dislocation density, the degree of dislocation entanglement, and ultimately the yield strength of the material.

EDGE DISLOCATIONS

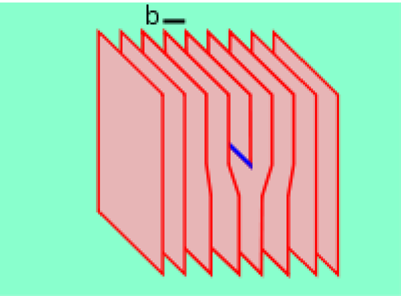


Figure B Schematic diagram (lattice planes) showing an edge dislocation. Burgers vector in black, dislocation line in blue.

An edge dislocation is a defect where an extra half-plane of atoms is introduced mid way through the crystal, distorting nearby planes of atoms. When enough force is applied from one side of the crystal structure, this extra plane passes through planes of atoms breaking and joining bonds with them until it reaches the grain boundary. A simple schematic diagram of such atomic planes can be used to illustrate lattice defects such as dislocations. (Figure B represents the "extra half-plane" concept of an edge type dislocation). The dislocation has two properties, a line direction, which is the direction running along the bottom of the extra half plane, and the Burgers vector which describes the magnitude and direction of distortion to the lattice. In an edge dislocation, the Burgers vector is perpendicular to the line direction. (see also Jog (dislocations))

The stresses caused by an edge dislocation are complex due to its inherent asymmetry. These stresses are described by three equations:

$$\sigma_{xx} = \frac{-\mu b}{2\pi(1-\nu)} \frac{y(3x^2+y^2)}{(x^2+y^2)^2}$$

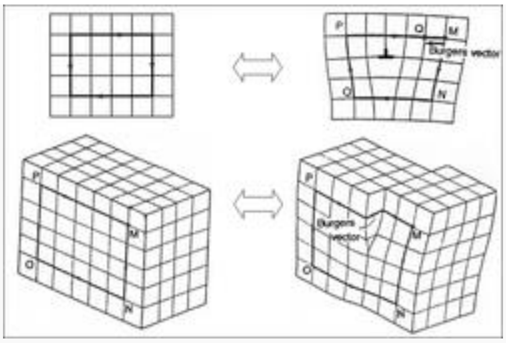
$$\sigma_{yy} = \frac{\mu b}{2\pi(1-\nu)} \frac{y(x^2-y^2)}{(x^2+y^2)^2}$$

$$\tau_{xy} = \frac{\mu b}{2\pi(1-\nu)} \frac{x(x^2-y^2)}{(x^2+y^2)^2}$$

where μ is the shear modulus of the material, b is the Burgers vector, ν is Poisson's ratio and x and y are coordinates.

These equations suggest a vertically oriented dumbbell of stresses surrounding the dislocation, with compression experienced by the atoms near the "extra" plane, and tension experienced by those atoms near the "missing" plane.

SCREW DISLOCATIONS



Top right: edge dislocation.
Bottom right: screw dislocation.

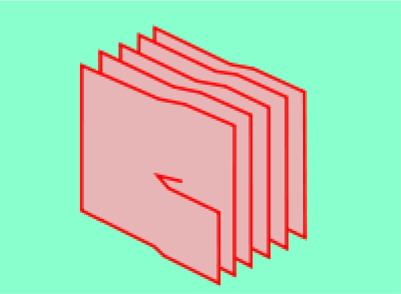


Figure C Schematic diagram (lattice planes) showing a screw dislocation.

A *screw dislocation* is much harder to visualize. Imagine cutting a crystal along a plane and slipping one half across the other by a lattice vector, the halves fitting back together without leaving a defect. If the cut only goes part way through the crystal, and then slipped, the boundary of the cut is a screw dislocation. It comprises a structure in which a helical path is traced around the linear defect (dislocation line) by the atomic planes in the crystal lattice (Figure C). Perhaps the closest analogy is a spiral-sliced ham. In pure screw dislocations, the Burgers vector is parallel to the line direction.

Despite the difficulty in visualization, the stresses caused by a screw dislocation are less complex than those of an edge dislocation. These stresses need only one equation, as symmetry allows only one radial coordinate to be used:

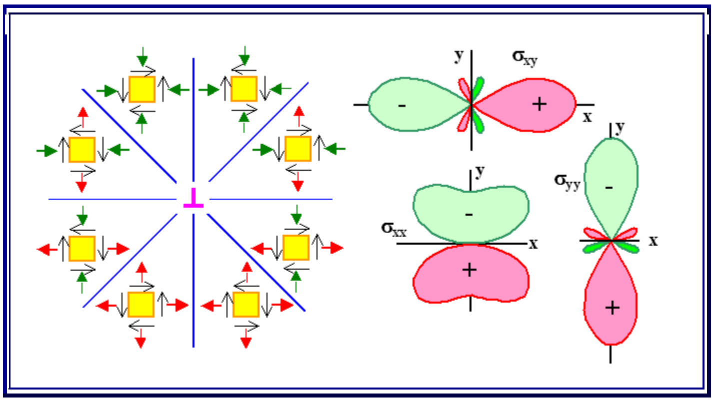
$$\tau_r = \frac{-\mu b}{2\pi r}$$

where μ is the shear modulus of the material, b is the Burgers vector, and r is a radial coordinate. This equation suggests a long cylinder of stress radiating outward from the cylinder and decreasing with distance. Please note, this simple model results in an infinite value for the core of the dislocation at r=0 and so it is only valid for stresses outside of the core of the dislocation. If the Burgers vector is very large, the core may actually be empty resulting in a micropipe, as commonly observed in silicon carbide.

STRESS FIELD AROUND AN EDGE DISLOCATION

Here is a well known representation of the stress field surrounding an edge dislocation.

On the left half of the picture, the stresses on the elementary cube are shown around the dislocation. Since there is no stress perpendicular to the image plane, a two-dimensional representation is sufficient. On the right half, contours of equal stress are shown for the normal component and the shear components of the stress tensor.



ULTRASONICS

NON DESTRUCTIVE TESTING AND APPLICATIONS

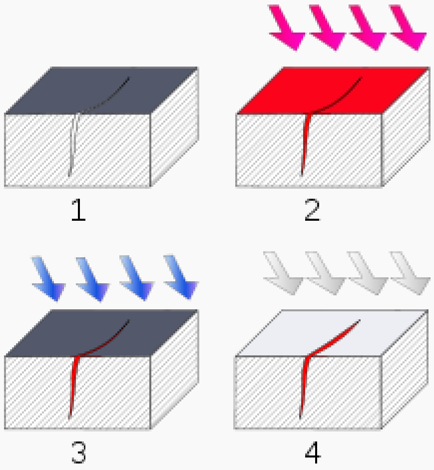
Nondestructive testing or Non-destructive testing (NDT) is a wide group of analysis techniques used in science and industry to evaluate the properties of a material, component or system without causing damage. The terms Nondestructive examination (NDE), Nondestructive inspection (NDI), and Nondestructive evaluation (NDE) are also commonly used to describe this technology. Because NDT does not permanently alter the article being inspected, it is a highly-valuable technique that can save both money and time in product evaluation, troubleshooting, and research. Common NDT methods include ultrasonic, magnetic-particle, liquid penetrant, radiographic, remote visual inspection (RVI), eddy-current testing, and low coherence interferometry. NDT is a commonly-used tool in forensic engineering, mechanical engineering, electrical engineering, civil engineering, systems engineering, aeronautical engineering, medicine, and art.

Methods

NDT methods may rely upon use of electromagnetic radiation, sound, and inherent properties of materials to examine samples. This includes some kinds of microscopy to examine external surfaces in detail, although sample preparation techniques for metallography, optical microscopy and electron microscopy are generally destructive as the surfaces must be made smooth through polishing or the sample must be electron transparent in thickness. The inside of a sample can be examined with penetrating electromagnetic radiation, such as X-rays or3D X-rays for volumetric inspection. Sound waves are utilized in the case of ultrasonic testing. Contrast between a defect and the bulk of the sample may be enhanced for visual examination by the unaided eye by using liquids to penetrate fatigue cracks. One method (liquid penetrant testing) involves using dyes, fluorescent or non-fluorescing, in fluids for non-magnetic materials, usually metals. Another commonly used method for magnetic materials involves using a liquid suspension of fine iron particles applied to a part while it is in an externally applied magnetic field (magnetic-particle testing). Thermoelectric effect (or use of the Seebeck effect) uses thermal properties of an alloy to quickly and easily characterize many alloys. The chemical test, or chemical spot test method, utilizes application of sensitive chemicals that can indicate the presence of individual alloying elements.

Applications

Weld verification



1. Section of material with a surface-breaking crack that is not visible to the naked eye.
2. Penetrant is applied to the surface.
3. Excess penetrant is removed.
4. Developer is applied, rendering the crack visible.

In manufacturing, welds are commonly used to join two or more metal surfaces. Because these connections may encounter loads and fatigue during product lifetime, there is a chance that they may fail if not created to proper specification. For example, the base metal must reach a certain temperature during the welding process, must cool at a specific rate, and must be welded with compatible materials or the joint may not be strong enough to hold the surfaces together, or cracks may form in the weld causing it to fail. The typical welding defects, lack of fusion of the weld to the base metal, cracks or porosity inside the weld, and variations in weld density, could cause a structure to break or a pipeline to rupture.

Welds may be tested using NDT techniques such as industrial radiography or industrial CT scanning using X-rays or gamma rays, ultrasonic testing, liquid penetrant testing or via eddy current. In a proper weld, these tests would indicate a lack of cracks in the radiograph, show clear passage of sound through the weld and back, or indicate a clear surface without penetrant captured in cracks.

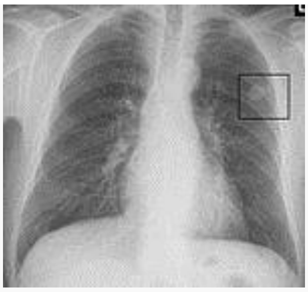
Welding techniques may also be actively monitored with acoustic emission techniques before production to design the best set of parameters to use to properly join two materials.

Structural mechanics

Structures can be complex systems that undergo different loads during their lifetime. Some complex structures, such as the turbo machinery in a liquid-fuel rocket, can also cost millions of dollars. Engineers will commonly model these structures as coupled second-order systems, approximating dynamic structure components with springs, masses, and dampers. These sets of differential equations can be used to derive a transfer function that models the behaviour of the system.

In NDT, the structure undergoes a dynamic input, such as the tap of a hammer or a controlled impulse. Key properties, such as displacement or acceleration at different points of the structure, are measured as the corresponding output. This output is recorded and compared to the corresponding output given by the transfer function and the known input. Differences may indicate an inappropriate model (which may alert engineers to unpredicted instabilities or performance outside of tolerances), failed components, or an inadequate control system.

Radiography in medicine



Chest radiography indicating a peripheral bronchial carcinoma.

As a system, the human body is difficult to model as a complete transfer function. Elements of the body, however, such as bones or molecules, have a known response to certain radiographic inputs, such as X-rays or magnetic resonance. Coupled with the controlled introduction of a known element, such as digested barium, radiography can be used to image parts or functions of the body by measuring and interpreting the response to the radiographic input. In this manner, many bone fractures and diseases may be detected and localized in preparation for treatment. X-rays may also be used to examine the interior of mechanical systems in manufacturing using NDT techniques, as well.

POSSIBLE QUESTIONS

PART-B (10 Marks)

1. Describe various classifications of defects with a clear picture.
2. Explain about Non destructive testing and applications.
3. Explain the experimental facts on F-centers.
4. Explain the following: (i) Points defect, (ii) The Schottky defect & (iii) F center
5. Explain the following: i) Colour centers, ii) Production of colour by X-rays & iii) Points defect
6. Explain the following: i) Shear strength of materials and (ii) Edge dislocation.
7. Explain the various classifications of crystal defects.
8. What is Ultrasonics? Explain a Non- destructive testing along with its applications.
9. What do you mean by dislocations? Explain Shear strength and Stress field around an edge dislocations

KARPAGAM ACADEMY OF HIGHER EDUCATION,COIMBATORE-21

DEPARTMENT OF PHYSICS

CLASS: I M.Sc., PHYSICS (2019-2021)

PART – A Online Examination (1 mark questions)
SUBJECT: CONDENSED MATTER PHYSICS
SUBJECT CODE: 19PHP101

UNIT - II

Questions	Option-1	Option-2	Option-3	Option-4	Key
Atomic packing factor is	Distance between two adjacent atoms	Projected area fraction of atoms on a plane	Volume fraction of atoms in cell	None	Volume fraction of atoms in cell
Schottky-defect in ceramic material is	Interstitial impurity	Vacancy-interstitial pair of cations	Pair of nearby cation and anion vacancies	Substitutional impurity	Pair of nearby cation and anion vacancies
Theoretical strength is about ___________ times to average real strength of a material.	1	10	100	1000	100
Hooke’s law	Elastic range, strain is proportional to stress		Plastic range, strain is proportional to stress	None	Elastic range, strain is proportional to stress
Following is not the 2-dimensional imperfection	Twin boundary	Dislocation	Surface	Grain boundary	Dislocation
Figure out the odd one in the following	Frenkel defect	Tilt boundary	Twist boundary	Stacking fault	Frenkel defect
Thermodynamically stable defects	Point defects	Line defects	Surface defects	Volume defects	Point defects
Taylor dislocation can not move by the following way	Slip	Climb	Cross-slip	All	Climb
Conservative movement of dislocations	Slip	Climb	Both slip and climb	none	Slip
Burger’s vector changes with	Kind of dislocation	Length of dislocation	Both kind and length of dislocation	None	None
Which of the following is false?	Line defects are thermodynamically	Dislocation can end inside a crystal without	ABC ABC ABC…is stacking sequence for HCP	All	All

	stable	forming loop	crystal		
Average frequency of atomic vibrations in a solid (in Hz)	10ˆ -12	10ˆ -13	10ˆ 12	10ˆ 13	10ˆ 13
Requirement for cross-slip movement of dislocation	Preferred slip plane	Preferred slip direction	No preferred slip plane	No preferred slip direction	No preferred slip plane
Beneficial property of foreign particles	Reduces density	Act as stress raisers	Obstructs dislocation motion	None	Obstructs dislocation motion
Stacking fault energies are in the range of	0.01-0.1 J/m2	0.01-0.1 J/cm2	0.1-10 J/m2	0.1-10 J/m2	0.01-0.1 J/m2
Frankel and Schottky imperfections are	dislocations in ionic crystals.	Grain boundaries in covalent crystals.	Vacancies in ionic crystals.	Vacancies in covalent crystals.	Vacancies in ionic crystals.
In normalizing, one of the following is not correct:	it relieves internal stresses	it produces a uniform structure.	the rate of cooling is rapid	the rate of cooling is slow.	the rate of cooling is slow.
Imperfection arising due to the displacement of an ion from a regular site to an interstitial site maintaining overall electrical neutrality of the ionic crystal is called.	Frenkel imperfection	Schottky imperfection	Point imperfection	Volume imperfection	Frenkel imperfection
Annealing is generally done to impart	hardness to the material	softness to the material	brittleness to the material	high conductivity to the material	softness to the material
Which of the following processes is used to harden a steel?	Normalizing	Annealing	Carburizing	Quenching	Quenching
The steady state conditions in diffusion are governed by	Fick’s second law.	Fick’s first law.	both (A) and (B).	Maxwell-Boltzmann’s law.	Fick’s first law.
A pair of one cation and one anion missing in a crystal of the type AB is called	Schottky defect.	Frenkel defect.	Pair of vacancies.	None of these.	Schottky defect.
The property of a material by which it can be drawn into wires is known as	ductility	elasticity	softness	tempering	ductility

Malleability of a metal is the	ability to withstand compressive stresses	ability to withstand deformation under shear	property by which a material can be cold-worked	ability to undergo permanent deformation	ability to undergo permanent deformation
The hardness of quenched Martensite	increases with increasing carbon percentage.		first increases and then remains almost constant as the carbon percentage increases.	first increases and then decreases as carbon percentage increases.	first increases and then remains almost constant as the carbon percentage increases.
Missing of one cation and one anion in an ionic crystal (having charge neutrality) is called	Frenkel imperfections.	Compositional imperfections.	Electronic imperfections.	Schottky imperfections.	Schottky imperfections.
Ultrasonic waves have frequency	as that of audible range	above audible range	below audible range	below as well as above audible range	above audible range
Ultrasonic waves are produced by utilizing	piezoelectric effect	Peltier effect	Doppler effects	magneto-optic effect	piezoelectric effect
The velocity of ultrasonic waves is generally greater in solids than in gases because	the density of solids is high but the elasticity is low	both the density and the elasticity of solids are low	the density of solids is low but the elasticity is high	both the density and elasticity of solids are high	both the density and elasticity of solids are high
Ultrasonic waves travel with a velocity	equal to the velocity of light	more than velocity of sound waves	equal to the velocity of sound waves	less than the velocity of sound waves	equal to the velocity of sound waves
Ultrasonic waves produced in a medium can be detected by	a telephone	Kundt’s tube	discharge tube	spectrometer	Kundt’s tube
Ultrasonic waves are used for stirring liquid solutions because	they do not cause chemical reactions	they cause chemical reactions	they produce perfectly homogenous solutions	they produce heating	they produce perfectly homogenous solutions
The waves used in	microwav	light	sound	ultrasonic	ultrasonic

sonography are	es	waves	waves	waves	waves
The wavelength of a wave produced in air is 0.60 cm. and it travels with a velocity 300 m/s. Then it is,	ultrasonic waves	sound waves	light waves	micro waves	ultrasonic waves
The wavelength of ultrasonic waves in air is in the order of	1 cm	5 × 10- 6 m	5 × 10 4 m	1 × 10 6 m	1 cm
The instrument used to measure the depth of the sea using ultrasonic waves is	lactometer	speedometer	galvanometer	fathometer	fathometer
Bats detect the obstacles in their path by receiving the reflected_______.	infrasonic waves	radio waves	electromagnetic waves	ultrasonic waves	ultrasonic waves
The frequency which is not audible to the human ear is	50 Hz	500 Hz	5000 Hz	50,000 Hz	50,000 Hz
The technique used by bats to find their way or to locate food--------	SONAR	RADAR	Echo location	Flapping	Echo location
The audible range of sound for human ear	below 20 Hz	above 20 kHz	20 Hz to 20 kHz	none of the above	20 Hz to 20 kHz
The frequency of infrasonic sound is	above 20 Hz	above 20 kHz	20 Hz to 20 kHz	below 20 Hz	below 20 Hz
You would generally select a high frequency ultrasound transducer to get	better tissue penetration	better image detail	faster imaging	decreased attenuation	better image detail
The wavelength of ultrasonic waves in air is 1.65 cm. Its frequency is :	20 Hz	200 Hz	2000 Hz	20000 Hz	20000 Hz
In ultrasound imaging, increasing the number of scan times in the image will generally	increase imaging depth	Increase visibility of anatomical detail	increase pulse velocity	none of the above	Increase visibility of anatomical detail
When using Doppler ultrasound to determine the blood flow velocity it is necessary for the equipment operator to make specific adjustment unique to the Doppler function for	transducer frequency	th of vessel	direction of vessel	size of the vessel.	direction of vessel
State the correct answer	ultrasonic	ultrasonic	ultrasonic	ultrasonic	ultrasonic

	are sound waves of very long wavelength	are sound waves of very high frequency	waves moves faster than sound wave	waves moves with the same velocity as sound waves	waves moves with the same velocity as sound waves
Wavelength of ultrasonic waves in air is of the order of 5 × 10- 3 m. Its frequency is	165 Hz	68 × 103 Hz	1.5 × 10- 9 Hz	170 Hz	68 × 103 Hz
Supersonic plane flies	with the speed less than the speed of sound	with the speed of sound	with the speed of greater than the sound	with the speed of light.	with the speed of sound
Bats flying in dark can avoid obstacles because of	infrasonic	ultrasonic waves	bats can see at night	none of the above.	ultrasonic waves
The waves that are produced during earthquake are called	infrasonic waves	ultrasonic waves	radio waves	micro waves.	infrasonic waves
Ultrasonic, infrasonic and audio waves travel through a medium with speed vu, vi and va respectively then	vu = vi = va	vu > va > vi	vu > va > vi	va ≤ vu and vu ≈ vi	vu = vi = va
Ultrasonics are	e.m.w	Elastic waves	Mechanical waves	Mechanical waves	Mechanical waves
Ultrasonic's have the characteristics of	Long wavelength	High frequency	Low frequency	Velocity equal to c	High frequency
The properties can be measured using ultrasonic's	Flaws of the solid	Thickness of the metal plate	Distance of the objects	All the above	All the above
Ultrasonic possess properties like	Having high frequency	Travel long distances	Reflects back when medium changes	All the above	All the above
Who discovered piezoelectric effect ?	J.J. Thomson	Curie brothers	Earnest Rutherford	Sommerfeld Arnold	Curie brothers
IN SONAR, type of signal is used to detect the objects is	electromagnetic waves	ultrasonic waves	infra-red radiation	ultrasonic let radiation	ultrasonic waves
Normally the intensity of ultrasonic waves are of the order of	2 - 3 kW/m2	3 - 4 kW/m2	4 - 5 kW/m2	1 - 2 kW/m2	1 - 2 kW/m2
Piezoelectric crystals like	asymmetri	symmetric	isotropic	anisotropic	asymmetric

quartz, Tourmaline are by nature	c				
The plates of the quartz crystal cut perpendicular to the z-axis known as	Y - cut crystal	Z - cut crystal	X - cut crystal	Y -Z cut crystal	Z - cut crystal

UNIT-II
SYLLABUS

Theory of Dielectrics, Piezoelectrics and Ferroelectrics Dipole moment – Polarization – the electric field of a dipole – local electric field at an atom – Clausius – Mosotti equation - Dielectric constants and its measurements - Polarizability – The Classical theory of electronic polarizability – dipolar polarizability – Ferro electricity – Dipole theory of ferroelectricity – Piezoelectricity.

THEORY OF DIELECTRICS

Dielectrics are the insulating materials having electric dipole moment permanently or temporarily by applying the electric field. These are mainly used to store electrical energy and used as electrical insulators. All dielectrics are electrical insulators, but all electrical insulators need not to be dielectrics.

Dielectrics are non - metallic materials of high specific resistance and have negative temperature coefficient of resistance.

BASIC DEFINITIONS

Electric flux density (D)
The number of electric lines passing through the unit area of cross section.

$$D = [\phi / A] \quad \textit{Unit:} \text{ Coulomb m}^{-2}$$

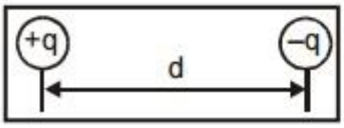
Permittivity

It is the ratio of electric displacement in a dielectric medium to the applied electric field strength.

$$\varepsilon = \frac{D}{E} \quad \text{for a dielectric medium} \quad \varepsilon_r >> 1$$

Dipole moment
Dipole moment is defined as the product of charge and distance between two changes.

$$\mu = q \times d$$



Unit : Coulomb meter.

Polarization

The separation of negative and positive charges is called polarization. i.e., the i.e., process of producing electric dipoles by an electric field is called polarization

$$P = \frac{N\mu}{V} = N\mu \qquad \text{[for unit volume V=1]}$$

Polarization vector

If “ ” is the average dipole moment per molecule and “N” is the number of molecules per unit volume then the polarization of the solid is given by the polarization vector P and it can be written as

$$P = \frac{N\mu}{V} = N\mu \qquad \text{[for unit volume V=1]}$$

The polarization vector is the dipole moment per unit volume of the dielectric material.

Polar and Non-polar Molecules

Polar Molecules

Polar Molecules which are having permanent dipole moment even in the absence of an applied field are called polar molecules.

Example: H2O, HCl, CO.

Non-polar Molecules

Molecules which do not have permanent dipole moment, but they have induced dipole moment in the presence of applied electric field are called non - polar molecules.

Example: O_2, H_2, N_2

Piezoelectrics

1)There are four different types of polarization.
2) Electronic (or) induced polarization
3) Ionic (or) atomic polarization
4) Orientation (or) dipolar polarization
5) Space - Charge (or) interfacial polarization

Electronic Polarization

Electronic Polarization occurs due to the displacement of positively charged nucleus and negatively charged electron in opposite directions by an external electric field. It creates a dipole moment in the dielectric. This is called electronic polarization.

The induced dipole moment, $\mu_e = \alpha_e E$ ...(1)

where α_e - Electronic polarisability.

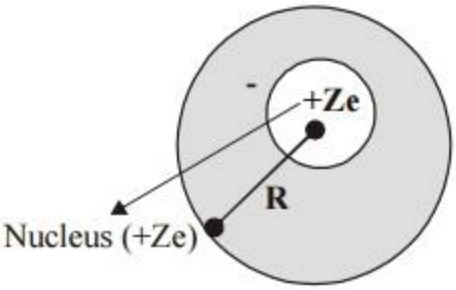
E - Electric field Strength.

It is proportional to volume of the atoms and is independent of temperature.

Calculation of electronic polarization(αe)

Consider an atom of a dielectric material of nuclear charge (Ze). The electrons of charge (–Ze) are distributed uniformly throughout the atom (Sphere) of radius R as shown in figure.

With out field



(a) Without Field

Fig.4.1 Electronic polarization

$$\left.\begin{matrix}\text{Charge density of the charged} \\ \text{sphere (electrons)of radius R}\end{matrix}\right\} = \frac{\text{Total charge of sphere with radius R}}{\text{Volume}}$$

$$= \frac{-Ze}{\frac{4}{3}\pi R^3}$$

$$= \frac{-3Ze}{4\pi R^3} \quad \ldots(1)$$

Ferroelectrics Dipole moment

It is a characteristic of certain materials that have a spontaneous electric polarization that can be reversed by the application of an external electric field.[1][2] All ferroelectrics are pyroelectric, with the additional property that their natural electrical polarization is reversible. The term is used in analogy to ferromagnetism, in which a material exhibits a permanent magnetic moment. Ferromagnetism was already known when ferroelectricity was discovered in 1920 in Rochelle salt by Valasek.[3] Thus, the prefix ferro, meaning iron, was used to describe the property despite the fact that most ferroelectric materials do not contain iron.

POLARIZABILITY

The Classical theory of electronic polarizability – Dielectric constant, property of an electrical insulating material (adielectric) equal to the ratio of the capacitance of a capacitor filled with the given material to the capacitance of an identical capacitor in a vacuum without the dielectric material. The insertion of a dielectric between the plates of, say, a parallel-plate capacitor always increases its capacitance, or ability to store opposite charges on each plate, compared with this ability when the plates are separated by a vacuum. If C is the value of the capacitance of a capacitor filled with a given dielectric and C_0 is the capacitance of an identical capacitor in a vacuum, the dielectric constant, symbolized by the Greek letter kappa, κ, is simply expressed as $\kappa = C/C_0$. The dielectric constant is a number without dimensions. It denotes a large-scale property of dielectrics without specifying the electrical behaviour on the atomicscale.
The value of the static dielectric constant of any material is always greater than one, its value for a vacuum. The value of the dielectric constant at room temperature (25° C, or 77° F) is 1.00059 for air, 2.25 for paraffin, 78.2 for water, and about 2,000 for barium titanate($BaTiO_3$) when the electric field is applied perpendicularly to the principal axis of the crystal. Because the value of the dielectric constant for air is nearly the same as that for a vacuum, for all practical purposes air does not increase the capacitance of a capacitor. Dielectric constants of liquids and solids may be determined by comparing the value of the capacitance when the dielectric is in place to its value when the capacitor is filled with air.
The dielectric constant is sometimes called relative permittivity or specific inductive capacity. In the centimetre–gram–second system the dielectric constant is identical to the permittivity.

Dipolar polarizability – Dielectric constant, property of an electrical insulating material (adielectric) equal to the ratio of the capacitance of a capacitor filled with the given material to the capacitance of an identical capacitor in a vacuum without the dielectric material. The insertion of a dielectric between the plates of, say, a parallel-plate capacitor always increases its capacitance, or ability to store opposite charges on each plate, compared with this ability when the plates are separated by a vacuum. If C is the value of the capacitance of a capacitor filled with a given dielectric and C_0 is the capacitance of an identical capacitor in a vacuum, the dielectric constant, symbolized by the Greek letter kappa, κ, is simply expressed as $\kappa = C/C_0$. The dielectric constant is a number without dimensions. It denotes a large-scale property of dielectrics without specifying the electrical behaviour on the atomicscale.

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Ferro electricity

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 microscopies and everyday uses such as acting as the ignition source for cigarette lighters

USES

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

POSSIBLE QUESTIONS

1. Describe quantum theory of paramagnetism.
2. Explain the free electron theory of metals and Debye's equation.
3. Explain the Langevin theory of paramagnetism
4. Explain Weiss molecular field theory.
5. Give an account of Neel's theory of antiferromagnetism and show how ferromagnetic behaviour of ferrites can be explained from Neel's theory.
6. How to measure the resistivity of metals? Give the explanation of free electron theory of metals
7. What do you mean by specific heat capacity? Explain the superconductivity with any two significant properties.
8. What is energy gap of metals? Explain BCS theory and Josephson effect of superconductors.
9. Write the experimental techniques to study the magnetic properties.

KARPAGAM ACADEMY OF HIGHER EDUCATION,COIMBATORE-21

DEPARTMENT OF PHYSICS

CLASS: I M.Sc., PHYSICS (2019-2021)

PART – A Online Examination (1 mark questions)
SUBJECT: CONDENSED MATTER PHYSICS
SUBJECT CODE: 19PHP101

UNIT - III

Questions	Option-1	Option-2	Option-3	Option-4	Key
The SI unit of heat capacity is	joule	joule ⁄ kilogram	joule ⁄ (kilogram × kelvin)	joule ⁄ kelvin	joule ⁄ kelvin
Aluminum has the specific heat capacity of	450 J kg^{-1} °C^{-1}	900 J kg^{-1} °C^{-1}	1350 J kg^{-1} °C^{-1}	1800 J kg^{-1} °C^{-1}	900 J kg^{-1} °C^{-1}
In a laboratory, bunsen burner is used to increase the temperature of lime from 10 °C to 50 °C with the thermal energy of 80000 J. If the mass of the lime is 20 kg the specific heat capacity of the lime would be	25 J kg^{-1} °C^{-1}	50 J kg^{-1} °C^{-1}	75 J kg^{-1} °C^{-1}	100 J kg^{-1} °C^{-1}	100 J kg^{-1} °C^{-1}
The heat capacity of sodium metal is 1500 J K^{-1}, if the mass of the sodium metal is 75 kg, the specific heat capacity would be	10 J kg^{-1} °C^{-1}	20 J kg^{-1} °C^{-1}	40 J kg^{-1} °C^{-1}	80 J kg^{-1} °C^{-1}	20 J kg^{-1} °C^{-1}
The internal energy comprises of two types of energies, those are	mechanical and electrical energy	magnetic and electrical energy	kinetic and potential energy	kinetic and magnetic energy	kinetic and potential energy
What substance is attracted to a magnet?	silver	lead	water	iron	iron
What characteristics do magnetic substances have?	They can give a “shock” when you touch them.	They can push or pull objects they are not touching.	They are always black and cold to touch.	They fall faster than other objects when you drop them.	They can push or pull objects they are not touching.
Ancient people discovered magnetic rocks called lodestone. What did they use them for?	to start fires	compasses	sculptures	telephone receivers	compasses
What must happen for an electromagnet to have a magnetic field?	It must be heated.	It has to be touching	It must be lined up with	It must be connected to an	It must be connected to an electrical

		another magnet.	Earth’s magnetic field.	electrical source.	source.
What happens when two north poles of magnets are placed together?	They repel.	They attract.	They cancel each other out.	The strength of the magnet is doubled.	They repel.
How is Earth’s magnetic field similar to that of a magnet?	It has North and South poles.	It is hundreds of miles long.	It is made in Earth’s core.	It is shaped like a horseshoe.	It has North and South poles.
What is our best evidence that Earth has a magnetic field?	All things fall toward Earth’s center.	A compass needle lines up with it.	Winds blow from east to west.	Earth’s oceans all have currents.	A compass needle lines up with it.
The study of phenomena at very low temperatures is called	heat transfer	morphology	crystallography	cryogenics	cryogenics
Thermal insulation is used to:	stop the flow of heat.	reduce the flow of heat.	absorb heat.	reverse the heat flow direction.	reverse the heat flow direction.
On which of the following factors does the resistivity of a material depend ?	Resistance of the conductor	Area of the conductor section	Length of the conductor	All of the above	All of the above
is a negatively charged particle present in an atom.	Proton	Neutron	Electron	None of the above	Electron
A perfect conductor has	zero conductivity	unity conductivity	infinite conductivity	none of the above	infinite conductivity
The metal having the lowest temperature coefficient of resistance is	gold	copper	aluminium	kanthal	gold
Commonly used conducting materials are	copper	aluminium	both (a) and (b)	copper and silver	both (a) and (b)
Which of the following materials is preferred for transmitting electrical energy over long distance ?	Copper	Aluminium	Steel reinforced copper	Steel reinforced aluminium	Steel reinforced aluminium
The kinetic energy of a bounded electron is	less than that of unbounded electron	greater than that of unbounded electron	equal to that of unbounded electron	infinite	less than that of unbounded electron

The conductivity of a conductor can be increased by	decreasing its temperature	increasing its temperature	decreasing its vibration	increasing its vibration	decreasing its temperature
Superconductivity is observed for	infrared frequencies	d.c. and low frequency	a.c. and high frequency	frequencies having no effect	d.c. and low frequency
The superconductivity is due to	the crystal structure having no atomic vibration at 0°K	all electrons interact in the super-conducting state	the electrons jump into nucleus at 0°K	none of the above	the crystal structure having no atomic vibration at 0°K
The value of critical field below the transition temperature will	increase	decrease	remain unchanged	any of the above	increase
In a superconductor the value of critical density depends upon	magnetic field strength	temperature	either (a) or (b)	both (a) and (b)	both (a) and (b)
Superconductors are becoming popular for use in	generating very strong magnetic field	manufacture of bubble memories	generating electrostatic field	generating regions free from magnetic field	generating very strong magnetic field
High resistivity materials are used in	precision instruments	heating elements	motor starters	all of the above	all of the above
Mercury as an electric contact material is	a liquid	a metal	a metal liquid	a gas	a metal liquid
An H.R.C. fuse is	a ceramic body having metal and caps	a wire of platinum	a heavy cross-section of copper or aluminium	a ceramic tube having carbon rod inside it	a ceramic body having metal and caps
Which of the following resistive materials has the lowest temperature co-efficient of resistance ?	Nichrome	Constantan	Kanthal	Molybdenum	Nichrome
The conductors have transport phenomena of electrons due to	electric field	magnetic field	electromagnetic field	none of the above	electric field
The transition temperature of mercury is	18.0°K	9.22°K	4.12°K	1.14'K	4.12°K
By increasing impurity content in the metal alloy the residual resistivity always	decreases	increases	remains constant	becomes temperature independe	increases

				nt	
The structure sensitive property of a super conductor is	critical magnetic field	transition temperature	critical current density	none of the above	critical current density
At transition temperature the value of critical field is	zero	negative real value	positive real value	complex value	zero
Which of the following is the poorest conductor of electricity ?	Carbon	Steel	Silver	Aluminium	Carbon
_______ has zero temperature co-efficient of resistance.	Aluminium	Carbon	Porcelain	Manganin	Manganin
In thermocouples which of the following pairs is commonly used ?	Copper-constantan	Aluminium-tin	Silver-German silver	Iron-steel	Copper-constantan
_______ is most commonly used for making magnetic recording tape	Silver nitrate	Ferric oxide	Small particles of iron	Silicon-iron	Ferric oxide
A good electric contact material should have all of the following properties except	high resistivity	high resistance to corrosion	good thermal conductivity	high melting point	high resistivity
Most of the common metals have ______ structure.	linear	hexagonal	orthorhombic	cubic	cubic
Which of the following affect greatly the resistivity of electrical conductors ?	Composition	Pressure	Size	Temperature	Composition
Addition of 0.3 to 4.5% silicon to iron ______ the electrical resistivity of iron.	increases	decreases	does not change	zero	increases
Super conductivity can be destroyed by	adding impurities	reducing temperatures	application of magnetic field	any of the above	application of magnetic field
In graphite, bonding is	covalent	metallic	Vander Waals	Vander Waals and covalent	Vander Waals and covalent
The resistivity of a metal is a function of temperature because	the amplitude of vibration of the atoms varies	the electron density varies with temperature	the electron gas density varies with temperature	None	the amplitude of vibration of the atoms varies with temperature

	with temperature				
The impurity atoms is semiconductors	inject more charge carriers	reduce the energy gap	increase the kinetic energy of valence electrons	all of the above	reduce the energy gap
Which of the following are non-conductors of electricity?	Non-metal solids except carbon	Air and most other gases	Pure water and liquids in general except mercury	All of the above	All of the above
Which of the following high resistance materials has the highest operating temperature ?	Kanthal	Manganin	Nichrome	Eureka	Kanthal
Low resistivity materials are used in	transformer, motor and generator windings	transmission and distribution lines	house wiring	all above applications	all above applications
Which of the following is an advantage of stranded conductor over equivalent single conductor ?	Less liability to kink	Greater flexibility	Less liability to break	All of the above	All of the above
Due to which of the following reasons copper and aluminium are not used for heating elements ?	Both have great tendency for oxidation	Both have low melting point	Very large length of wires will be required	All of the above	All of the above
Which of the following materials is used for making coils of standard resistances ?	Copper	Nichrome	Platinum	Manganin	Manganin
Substances whose specific resistance abruptly decreases at very low temperature are called	insulators	conductors	semiconductors	superconductors	superconductors
Which of the following materials is the best conductor of electricity ?	Tungsten	Aluminium	Copper	Carbon	Copper
The conduction of electricity, in semiconductors, takes place due to movement of	positive ions only	negative ions only	positive and negative ions	electrons and holes	electrons and holes
Which of the following is a	Phosphor	Rubber	Silicon	Aluminium	Silicon

semiconductor material ?	ous				
If the resistance of a conductor does not vary in accordance with Ohm's law it is known as	non-linear conductor	reverse conductor	bad-conductor	non-conductor	non-linear conductor
The forbidden gap in an insulator is	large	small	nil	any of the above	large
Which of the following factors affect resistivity of metals ?	Age hardening	Alloying	Temperature	All of the above	All of the above

UNIT-IV
SYLLABUS

FREE-ELECTRON THEORY OF METALS

The treatment of a metal as containing a gas of electrons completely free to move within it. The theory was originally proposed in 1900 to describe and correlate the electrical and thermal properties of metals. Later, quantum mechanics became the basis for the theory of most of the general properties of simple metals such as sodium, with one free electron per atom, magnesium with two, and aluminum with three. Transition metals, such as iron, have partially filled electronic *d* states and are not treated by the free-electron model.

Three years after J. J. Thomson's 1897 discovery of the electron, P. Drude suggested that the transport properties of metals might be understood by assuming that their electrons are free and in thermal equilibrium with their atoms. This theory was made more quantitative by H. A. Lorentz. Assuming that the mean free path of electrons was limited by collisions, he was able to derive Ohm's law for the electrical conductivity and obtain the ratio of thermal to electrical conductivity in excellent agreement with experiment. This ratio, divided by the absolute temperature, is called the Wiedemann-Franz ratio and had been observed to be universal 50 years earlier.

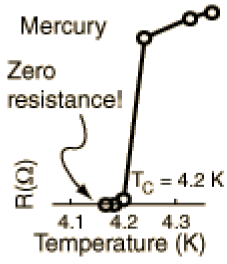
The theory, however, had two major shortcomings. First, it predicted a large component of the specific heat of a metal, not present in insulators, which was not observed. Second, comparison of the theory with experiment indicated that the mean free path of the electrons became extremely large at low temperatures; the model offered no justification.

In 1928 A. Sommerfeld revised Lorentz's treatment by using quantum statistics, which removed the difficulty of the specific heat without losing the successful description of transport properties. The resulting theory remains the basis for the understanding of most transport properties of metals and semiconductors. At about the same time, W. V. Houston and F. Bloch solved the quantum-mechanical wave equation for electrons in a regular periodic structure, finding that they could indeed have arbitrarily large mean free paths if there were no defects in the periodicity, thereby putting the free-electron theory on a firm basis.

Even in the context of a free-electron gas, there are strong Coulomb interactions between electrons which are frequently neglected in the free-electron theory of metals. This neglect was justified in the late 1950s by L. D. Landau, who asserted that, even with strong electron–electron interactions, there is a one-to-one correspondence between the excited states, called quasiparticle states, of the real system and the one-electron excitations from the ground state of the noninteracting electron gas. Thus, the formulations for free-electron theory still follow, but perhaps with modifications of parameters such as mass. Subsequent theory indicates that indeed these modification due to the electron-electron interaction are extremely small for the low-energy excitations present in thermal equilibrium, and so again the simplest theory succeeds for many properties, although substantial modifications are required for the higher-energy excitations caused by light. There are additional corrections, which are much larger than those from the electron-electron interaction, arising from the interaction between electrons and phonons, the quantum-mechanical term for lattice vibrations. In many metals these vibrations reduce the electron velocities by factors of as much as 2, increasing the electronic specific heat although they turn out not to modify the conductivity itself.

Another feature of the electron–phonon interaction is a resulting interaction among electrons, which is attractive and tends to cancel or exceed the repulsive electron-electron interaction. At low temperatures the net attraction binds electrons in pairs in a superconducting state. The theory of J. Bardeen, J. R. Schrieffer, and L. N. Cooper (the BCS theory of superconductivity), which first explained this phenomenon, is also a free-electron theory, but assumes that the free electrons have such a net attractive interaction. In contrast, it is generally believed that the high-temperature superconductors discovered in 1986 are very far from free-electron in character, and most workers do not believe that phonons are primarily responsible for the attractive interaction.

SUPERCONDUCTIVITY



If mercury is cooled below 4.1 K, it loses all electric resistance. This discovery of superconductivity by H. Kammerlingh Onnes in 1911 was followed by the observation of other metals, which exhibit zero resistivity below a certain critical temperature. The fact that the resistance is zero has been demonstrated by sustaining currents in superconducting lead rings for many years with no measurable reduction. An induced current in an ordinary metal ring would decay rapidly from the dissipation of ordinary resistance, but superconducting rings had exhibited a decay constant of over a billion years!

One of the properties of a superconductor is that it will exclude magnetic fields, a phenomenon called the Meissner effect.

The disappearance of electrical resistivity was modeled in terms of electron pairing in the crystal lattice by John Bardeen, Leon Cooper, and Robert Schrieffer in what is commonly called the BCS theory.

A new era in the study of superconductivity began in 1986 with the discovery of high critical temperature superconductors.

Critical Temperature for Superconductors

Material	T-Critical
Gallium	1.1 K
Aluminum	1.2 K
Indium	3.4 K
Tin	3.7 K
Mercury	4.2 K
Lead	7.2 K
Niobium	9.3 K
Niobium-Tin	17.9 K

La-Ba-Cu-oxide	30 K
Y-Ba-Cu-oxide	92 K
Tl-Ba-Cu-oxide	125 K

The critical temperature for superconductors is the temperature at which the electrical resistivity of a metal drops to zero. The transition is so sudden and complete that it appears to be a transition to a different phase of matter; this superconducting phase is described by the BCS theory. Several materials exhibit superconducting phase transitions at low temperatures. The highest critical temperature was about 23 K until the discovery in 1986 of some high temperature superconductors.

Materials with critical temperatures in the range 120 K have received a great deal of attention because they can be maintained in the superconducting state with liquid nitrogen (77 K).

Types I and II Superconductors

There are thirty pure metals, which exhibit zero resistivity at low temperatures and have the property of excluding magnetic fields from the interior of the superconductor (Meissner effect). They are called Type I superconductors. The superconductivity exists only below their critical temperatures and below a critical magnetic field strength. Type I superconductors are well described by the BCS theory.

Starting in 1930 with lead-bismuth alloys, a number of alloys were found which exhibited superconductivity; they are called Type II superconductors. They were found to have much higher critical fields and therefore could carry much higher current densities while remaining in the superconducting state.

The variations on barium-copper-oxide ceramics which achieved the superconducting state at much higher temperatures are often just referred to as high temperature superconductors and form a class of their own.

Type I Superconductors

The thirty pure metals listed at right below are called Type I superconductors. The identifying characteristics are zero electrical resistivity below a critical temperature, zero internal magnetic field (Meissner effect), and a critical magnetic field above which superconductivity ceases.

Mat.	Tc
Be	0
Rh	0
W	0.015
Ir	0.1
Lu	0.1
Hf	0.1
Ru	0.5
Os	0.7
Mo	0.92
Zr	0.546
Cd	0.56
U	0.2
Ti	0.39
Zn	0.85
Ga	1.083
Al	1.2
Pa	1.4
Th	1.4
Re	1.4
Tl	2.39
In	3.408
Sn	3.722
Hg	4.153
Ta	4.47
V	5.38
La	6.00
Pb	7.193
Tc	7.77
Nb	9.46

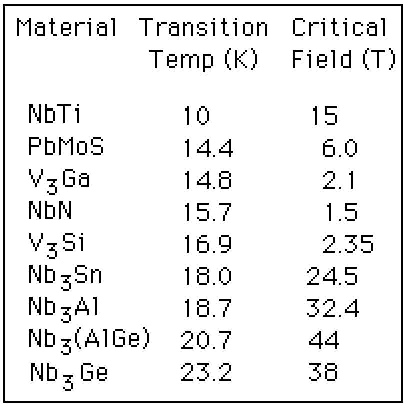
The superconductivity in Type I superconductors is modeled well by the BCS theory which relies upon electron pairs coupled by lattice vibration interactions. Remarkably, the best conductors at room temperature (gold, silver, and copper) do not become superconducting at all. They have the smallest lattice vibrations, so their behavior correlates well with the BCS Theory.

While instructive for understanding superconductivity, the Type I superconductors have been of limited practical usefulness because the critical magnetic fields are so small and the superconducting state disappears suddenly at that temperature. Type I superconductors are sometimes called "soft" superconductors while the Type II are "hard", maintaining the superconducting state to higher temperatures and magnetic fields.

Type II Superconductors

Superconductors made from alloys are called Type II superconductors. Besides being mechanically harder than Type I superconductors, they exhibit much higher critical magnetic fields. Type II superconductors such as niobium-titanium (NbTi) are used in the construction of high field superconducting magnets.

Type-II superconductors usually exist in a mixed state of normal and superconducting regions. This is sometimes called a vortex state, because vortices of superconducting currents surround filaments or cores of normal material.



Material	Transition Temp (K)	Critical Field (T)
NbTi	10	15
PbMoS	14.4	6.0
V_3Ga	14.8	2.1
NbN	15.7	1.5
V_3Si	16.9	2.35
Nb_3Sn	18.0	24.5
Nb_3Al	18.7	32.4
$Nb_3(AlGe)$	20.7	44
Nb_3Ge	23.2	38

From Blatt, Modern Physics

ELECTRON-PHONON INTERACTION

The strength of the electron-phonon interaction has been addressed in several ways, both via *ab initio* calculations and via analysis of experiment. A very early theoretical estimate was obtained within the rigid muffin-tin, using an empirical phonon model. Later a full potential LMTO calculation was performed to obtain *ab initio* phonon frequencies, eigenvectors and electron-phonon couplings in a frozen phonon approach.

The electron-phonon coupling has also been deduced from photoemission measurements for free, negatively charged, C60 molecule. In this approach the coupling strengths are deduced from the weights of the phonon satellites in the photoemission spectrum

The electron-phonon coupling can also be deduced from Raman scattering data. These estimates differ substantially from the once deduced from photoemission. We have therefore analyzed the methods for extracting the electron-phonon coupling from Raman scattering data and shown that the two types of experiment can be partly reconciled.

To obtain the electron-phonon coupling, it is important to also know the density of states, since this quantity enters as a multiplying factor. Different estimates of density of states have therefore been analyzed.

The theoretical estimates generally give a rather weak coupling to the low-lying Hg phonons in contradiction to the experimental estimates. The reason for this discrepance is not known.

COOPER PAIR

In condensed matter physics, a Cooper pair is the name given to electrons that are bound together at low temperatures in a certain manner first described in 1956 by Leon Cooper. Cooper showed that an arbitrarily small attraction between electrons in a metal can cause a paired state of electrons to have a lower energy than the Fermi energy, which implies that the pair is bound. In normal superconductors, this attraction is due to the electron - phonon interaction. The Cooper pair state is responsible for superconductivity, as described in the BCS theory developed by John Bardeen, John Schrieffer and Leon Cooper for which they shared the 1972 Nobel Prize.

The reason for the pairing can be seen from a simplified explanation. An electron in a metal normally behaves as a free particle. The electron is repelled from other electrons due to their similar charge, but it also attracts the positive ions that make up the rigid lattice of the metal. This attraction can distort the positively charged ion lattice in such a way as to attract other electrons (the electron-phonon interaction). At long distances this attraction between electrons due to the displaced ions can overcome the electrons' repulsion due to their negative charge, and cause them to pair-up.

The energy of the pairing interaction is quite weak, of the order of 10^{-3}eV, and thermal energy can easily break the pairs up. So only at low temperatures are a significant number of the electrons in a metal in Cooper pairs. The electrons in a pair are not necessarily close together; because the interaction is long range, paired electrons may still be many hundreds of nanometers apart. This distance is usually greater than the average inter electron distance, so many Cooper pairs can occupy the same space. Since electrons are spin-1/2 fermions, a Cooper pair is a boson, to which the Pauli exclusion principle doesn't apply, so they are allowed to be in the same state. The tendency for all the Cooper pairs in a body to 'condense' into the same ground quantum state is responsible for the peculiar properties of superconductivity.

Relationship to superconductivity

Cooper originally just considered the case of an isolated pair forming in a metal. When one considers the more realistic state consisting of many electrons forming pairs as is done in the full BCS Theory one finds that the pairing opens a gap in the continuous spectrum of allowed energy states of the electrons, meaning that all excitations of the system must possess some minimum amount of energy. This gap to excitations leads to superconductivity, since small excitations such as scattering of electrons are forbidden.

Herbert Fröhlich was first to suggest that the electrons might act as pairs coupled by lattice vibrations in the material. This was indicated by the isotope effect observed in superconductors. The isotope effect showed that materials with heavier ions (different nuclear isotopes) had lower superconducting transition temperatures. This can be explained nicely by the theory of Cooper pairing; since heavier ions are harder to move they would be less able to attract the electrons resulting in a smaller binding energy for Cooper pairs.

The pair are still Cooperic

if $k_1 = k_2$ and $k_1 - q = -(k_1 - q) = -(-k_2 - q) = -(k_2 + q)$

The theory of Cooper pairs is quite general and does not depend on the specific electron-phonon interaction. Condensed matter theorists have proposed pairing mechanisms based on other attractive interactions such as electron-exciton interactions or electron-plasmon interactions. Currently, none of these alternate pairing interactions has been observed in any material.

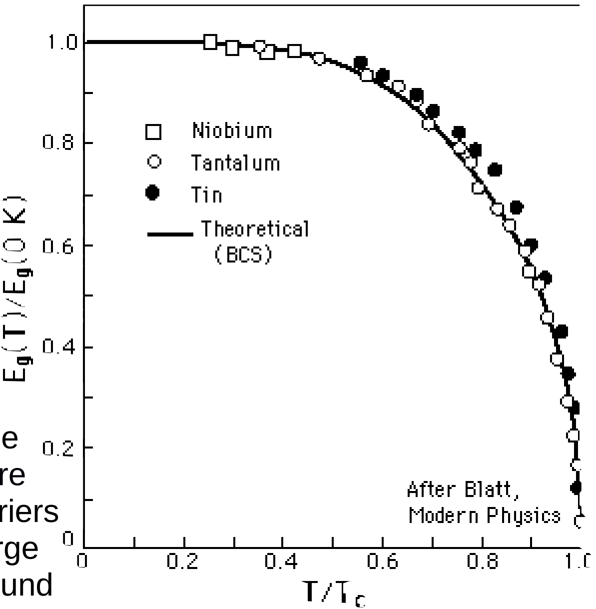
BCS theory

BCS theory is a microscopic theory of superconductivity, proposed by Bardeen, Cooper, and Schrieffer. It describes superconductivity as a microscopic effect caused by Bose condensation of pairs of electrons.

In many superconductors, the attractive interaction between electrons (necessary for pairing) is brought about indirectly by the interaction between the electrons and the vibrating crystal lattice (the phonons). Roughly speaking the picture is the following:

ENERGY GAP IN SUPERCONDUCTORS AS A FUNCTION OF TEMPERATURE

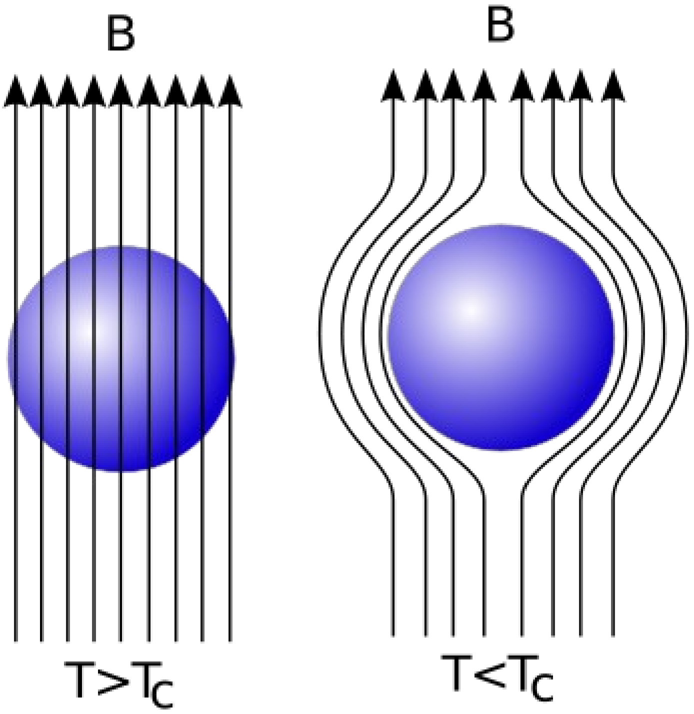
The effective energy gap in superconductors can be measured in microwave absorption experiments. The data at left offer general confirmation of the BCS theory of superconductivity. The data is attributed to Townsend and Sutton.



The reduction of the energy gap as you approach the critical temperature can be taken as an indication that the charge carriers have some sort of collective nature. That is, the charge carriers must consist of at least two things which are bound together, and the binding energy is weakening as you approach the critical temperature. Above the critical temperature, such collections do not exist, and normal resistivity prevails. This kind of evidence, along with the isotope effect which showed that the crystal lattice was involved, helped to suggest the picture of paired electrons bound together by phonon interactions with the lattice.

LONDON EQUATIONS

The London equations, developed by brothers Fritz and Heinz London in 1935, relate current to electromagnetic fields in and around a superconductor. Arguably the simplest meaningful description of superconducting phenomena, they form the genesis of almost any modern introductory text on the subject. A major triumph of the equations is their ability to explain the Meissner effect, wherein a material exponentially expels all internal magnetic fields as it crosses the superconducting threshold.



As a material drops below its superconducting critical temperature, magnetic fields within the material are expelled via the Meissner effect. The London equations give a quantitative explanation of this effect.

Formulations

There are two London equations when expressed in terms of measurable fields:

$$\frac{\partial \mathbf{j}_s}{\partial t} = \frac{n_s e^2}{m}\mathbf{E}, \qquad \nabla \times \mathbf{j}_s = -\frac{n_s e^2}{mc}\mathbf{B}.$$

Here $\mathbf{j}_s$ is the superconducting current, E and B are respectively the electric and magnetic fields within the superconductor, e is the charge of an electron, m is electron mass, and n_s is a phenenological constant loosely associated with a number density of superconducting carriers. Throughout this article Gaussian (cgs) units are employed.

On the other hand, if one is willing to abstract away slightly, both the expressions above can more neatly be written in terms of a single "London Equation" in terms of the vector potential A:

$$\mathbf{j}_s = -\frac{n_s e_s^2}{mc}\mathbf{A}.$$

The last equation suffers from only the disadvantage that it is not gauge invariant, but is true only in the London gauge, where the divergence of A is zero.

JOSEPHSON EFFECT

The Josephson effect is the phenomenon of current flow across two weakly coupled superconductors, separated by a very thin insulating barrier. This arrangement—two superconductors linked by a non-conducting barrier—is known as a Josephson junction; the current that crosses the barrier is the Josephson current. The terms are named after British physicist Brian David Josephson, who predicted the existence of the effect in 1962. It has important applications in quantum-mechanical circuits, such as SQUIDs.

The effect

The basic equations governing the dynamics of the Josephson effect are

$$U(t) = \frac{\hbar}{2e}\frac{\partial \phi}{\partial t}$$

(superconducting phase evolution equation)

$$I(t) = I_c \sin(\phi(t))$$

(Josephson or weak-link current-phase relation)

where $U(t)$ and $I(t)$ are the voltage and current across the Josephson junction, $\phi(t)$ is the "phase difference" across the junction (i.e., the difference in phase factor, or equivalently, argument, between the Ginzburg-Landau complex order parameter of the two superconductors comprising the junction), and I_c is a constant, the *critical current* of the junction. The critical current is an important phenomenological parameter of the device that can be affected by temperature as well as by an applied magnetic field. The physical constant, $\frac{h}{2e}$ is the magnetic flux quantum, the inverse of which is the Josephson constant.

The three main effects predicted by Josephson follow from these relations:

1. The DC Josephson effect. This refers to the phenomenon of a direct current crossing the insulator in the absence of any external electromagnetic field, owing to tunneling. This DC Josephson current is proportional to the sine of the phase difference across the insulator, and may take values between $-I_c$ and I_c.

2. The AC Josephson effect. With a fixed voltage U_{DC} across the junctions, the phase will vary linearly with time and the current will be an AC current with amplitude I_c and frequency $\frac{2e}{h} \cdot U_{DC}$.

The complete expression for the current drive I_{ext} becomes $I_{ext} = C_J \frac{dv}{dt} + I_J sin\phi + \frac{V}{R}$.

3. This means a Josephson junction can act as a perfect voltage-to-frequency converter.

4.The inverse AC Josephson effect. If the phase takes the form $\phi(t) = \phi_0 + n\omega t + a\sin(\omega t)$, the voltage and current will be

$$U(t) = \frac{\hbar}{2e}\omega(n + a\cos(\omega t)), \quad I(t) = I_c \sum_{m=-\infty}^{\infty} J_n(a)\sin(\phi_0 + (n+m)\omega t)$$

The DC components will then be

$$U_{DC} = n\frac{\hbar}{2e}\omega, \quad I(t) = I_c J_{-n}(a)\sin\phi_0$$

Hence, for distinct DC voltages, the junction may carry a DC current and the junction acts like a perfect frequency-to-voltage converter.

Applications

The Josephson effect has found wide usage, for example in the following areas:

- SQUIDs, or superconducting quantum interference devices, are very sensitive magnetometers that operate via the Josephson effect. They are widely used in science and engineering. (See main article: SQUID.)
- In precision metrology, the Josephson effect provides an exactly reproducible conversion between frequency and voltage. Since the frequency is already defined precisely and practically by the cesium standard, the Josephson effect is used, for most practical purposes, to give the definition of a volt (although, as of July 2007, this is not the official BIPM definition).
- Single-electron transistors are often constructed of superconducting materials, allowing use to be made of the Josephson effect to achieve novel effects. The resulting device is called a "superconducting single-electron transistor".
- Josephson junctions are integral in Superconducting quantum computing as qubits where the phase and charge act as the Conjugate variables.

CURIE'S LAW

In a paramagnetic material the magnetization of the material is directly proportional to an applied magnetic field. However, if the material is heated, this proportionality is reduced: for a fixed value of the field, the magnetization is inversely proportional to temperature. This fact is encapsulated by Curie's law:

$$\mathbf{M} = C \cdot \frac{\mathbf{B}}{T},$$

where

$\mathbf{M}$ is the resulting magnetisation

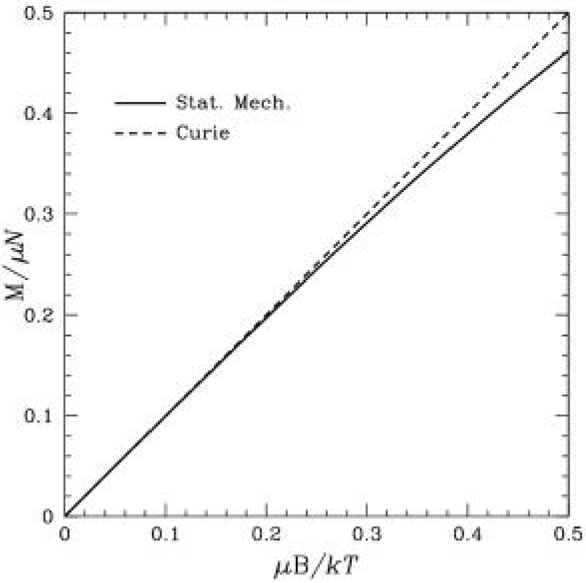
$\mathbf{B}$ is the magnetic field, measured in teslas

T is absolute temperature, measured in kelvins

C is a material-specific Curie constant

This relation was discovered experimentally (by fitting the results to a correctly guessed model) by Pierre Curie. It only holds for high temperatures, or weak magnetic fields. As the derivations below show, the magnetization saturates in the opposite limit of low temperatures, or strong fields.

Simple Derivation (Statistical Mechanics)



Magnetization of a paramagnet as a function of inverse temperature.

A simple model of a paramagnet concentrates on the particles which compose it, call them *paramagnetons*, which do not interact with each other. Each paramagneton has a magnetic moment given by $\vec{\mu}$. The energy of a magnetic moment in a magnetic field is given by

$$E = -\vec{\mu} \cdot \vec{B}$$

To simplify the calculation, we are going to work with a 2-state paramagneton: the particle may either align its magnetic moment with the magnetic field, or against it. So the only possible values of magnetic moment are then μ and $-\mu$. If so, then such a particle has only two possible energies

$$E_0 = -\mu B$$

and

$$E_1 = \mu B$$

When one seeks the magnetization of a paramagnet, one is interested in the likelihood of a paramagneton to align itself with the field. In other words, one seeks the expectation value of the magnetization μ:

$$\langle\mu\rangle = \mu P(\mu) + (-\mu)P(-\mu) = \frac{1}{Z}\left(\mu e^{\mu B\beta} - \mu e^{-\mu B\beta}\right) = \frac{2\mu}{Z}\sinh(\mu B\beta),$$

where the probability of a configuration is given by its Boltzmann factor, and the partition function Z provides the necessary normalization for probabilities (so that the sum of all of them is unity.) The partition function of one paramagneton is:

$$Z = \sum_{n=0,1} e^{-E_n\beta} = e^{\mu B\beta} + e^{-\mu B\beta} = 2\cosh(\mu B\beta)$$

Therefore, in this simple case we have:

$$\langle\mu\rangle = \mu\tanh(\mu B\beta)$$

This is magnetization of one paramagneton, the total magnetization of the solid is given by

$$M = N\langle\mu\rangle = N\mu\tanh\left(\frac{\mu B}{kT}\right)$$

The formula above is known as the Langevin Paramagnetic equation. Pierre Curie found an approximation to this law which applies to the relatively high temperatures and low, magnetic fields used in his experiments. Let's see what happens to the magnetization as we specialize it to large T and small B. As temperature increases and magnetic field decreases, the argument of hyperbolic tangent decreases. Another way to say this is

$$\left(\frac{\mu B}{kT}\right) \ll 1$$

this is sometimes called the Curie regime. We also know that if $|x| \ll 1$, then

$$\tanh x \approx x$$

So

$$\mathrm{M}(T \to \infty) = \frac{N\mu^2}{k}\frac{\mathbf{B}}{T}$$

Q.E.D., with a Curie constant given by $C = N\mu^2 / k$. Also, in the opposite regime of low temperatures or high fields, M tends to a maximum value of $N\mu$, corresponding to all the paramagnetons being completely aligned with the field.

FERROMAGNETISM

Iron, nickel, cobalt and some of the rare earths (gadolinium, dysprosium) exhibit a unique magnetic behavior which is called ferromagnetism because iron (ferrum in Latin) is the most common and most dramatic example. Samarium and neodymium in alloys with cobalt have been used to fabricate very strong rare-earth magnets.

Ferromagnetic materials exhibit a long-range ordering phenomenon at the atomic level which causes the unpaired electron spins to line up parallel with each other in a region called a domain. Within the domain, the magnetic field is intense, but in a bulk sample the material will usually be unmagnetized because the many domains will themselves be randomly oriented with respect to one another. Ferromagnetism manifests itself in the fact that a small externally imposed magnetic field, say from a solenoid, can cause the magnetic domains to line up with each other and the material is said to be magnetized. The driving magnetic field will then be increased by a large factor which is usually expressed as a relative permeability for the material. There are many practical applications of ferromagnetic materials, such as the electromagnet.

Ferromagnets will tend to stay magnetized to some extent after being subjected to an external magnetic field. This tendency to "remember their magnetic history" is called hysteresis. The fraction of the saturation magnetization which is retained when the driving field is removed is called the remanence of the material, and is an important factor in permanent magnets.

All ferromagnets have a maximum temperature where the ferromagnetic property disappears as a result of thermal agitation. This temperature is called the Curie temperature.

Ferromagnetic materials will respond mechanically to an impressed magnetic field, changing length slightly in the direction of the applied field. This property, called magnetostriction, leads to the familiar hum of transformers as they respond mechanically to 60 Hz AC voltages.

WEISS MOLECULAR FIELD

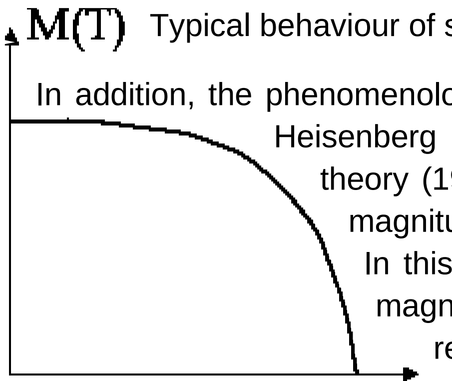
Some materials present very strong magnetization, typically in the order of the saturation magnetization, also in absence of external field, i.e. they present spontaneous magnetization. These kinds of materials are referred to as *ferromagnetic materials* (Fe, Co, Ni, Gd, alloys, etc.). Typical properties of some ferromagnetic materials can be found in Appendix A. The behavior of very small regions of ferromagnetic materials can be treated by following the same line of reasoning used for paramagnetism. With respect to the continuum model introduced in section 1.1.1, we are now dealing with phenomena occurring inside our elementary volume $dV_{\mathbf{r}}$, which involve the interactions between single spins. Here we report the theory developed by Weiss which is very similar to the one used for paramagnetism. In fact, the main difference stays in the postulation of an additional magnetic field H_w whose non magnetic (Maxwellian) origin is not investigated. This field was called *molecular field* by Weiss; by adding the field $H_\mathrm{w} = N_\mathrm{w} M$ (N_w is characteristic of the material) to the external field in Eq. (1.24), one ends up with the following equation:

$$M = M_s \, \mathcal{L} \left(\frac{\mu_0 m_0 (H_\mathrm{a} + N_\mathrm{w} \, M)}{kT} \right) \quad . \tag{1.28}$$

The latter equation can be linearized for high temperatures, which corresponds to small β as seen before. Then, one can find the well-known *Curie-Weiss law* that once again expresses the dependence of the susceptibility on the temperature

$$\chi \propto \frac{1}{T - T_c} \quad , \quad T_c = \frac{\mu_0 M_s m_0 N_\mathrm{w}}{3k} \quad , \tag{1.29}$$

where T_c is the Curie temperature, characteristic of the material. Thus, for temperatures $T > T_c$ the ferromagnetic materials behave like paramagnetic. For temperature $T < T_c$, one can use Eq. (1.28) to derive the relationship between the saturation magnetization M_s and the temperature T. The resulting relationship $M_s = M_s(T)$ behaves like in Fig. 1.2. This behavior qualitatively matches with experimental observations [5].



Typical behaviour of spontaneous magnetization as function of temperature

In addition, the phenomenological approach of molecular field was theoretically justified when Heisenberg introduced the exchange interaction on the basis of quantum theory (1931). Nevertheless, the Weiss theory gives information about the magnitude of magnetization, but nothing can be said about the direction. In this respect micromagnetics has the purpose to find the direction of magnetization at every location within the magnetic body. In this respect, for constant temperature, the magnetization vector $\mathbf{M}(\mathbf{r}, t)$ field can be written as

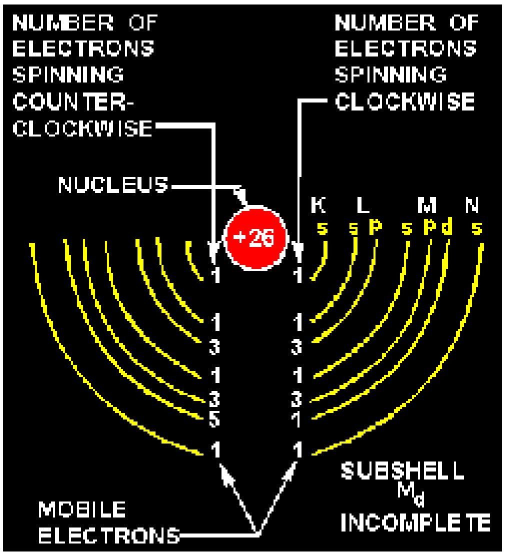
$$\mathbf{M}(\mathbf{r}, t) = M_s\, \mathbf{m}(\mathbf{r}, t) \quad , \tag{1.30}$$

where $\mathbf{m}(\mathbf{r}, t)$ is the magnetization unit-vector field.

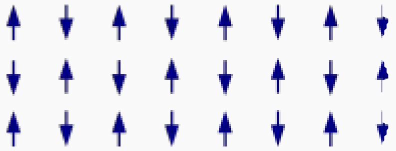
DOMAIN THEORY

A more modern theory of magnetism is based on the electron spin principle. From the study of atomic structure it is known that all matter is composed of vast quantities of atoms, each atom containing one or more orbital electrons. The electrons are considered to orbit in various shells and subshells depending upon their distance from the nucleus. The structure of the atom has previously been compared to the solar system, wherein the electrons orbiting the nucleus correspond to the planets orbiting the sun. Along with its orbital motion about the sun, each planet also revolves on its axis. It is believed that the electron also revolves on its axis as it orbits the nucleus of an atom.

It has been experimentally proven that an electron has a magnetic field about it along with an electric field. The effectiveness of the magnetic field of an atom is determined by the number of electrons spinning in each direction. If an atom has equal numbers of electrons spinning in opposite directions, the magnetic fields surrounding the electrons cancel one another, and the atom is unmagnetized. However, if more electrons spin in one direction than another, the atom is magnetized. An atom with an atomic number of 26, such as iron, has 26 protons in the nucleus and 26 revolving electrons orbiting its nucleus. If 13 electrons are spinning in a clockwise direction and 13 electrons are spinning in a counterclockwise direction, the opposing magnetic fields will be neutralized. When more than 13 electrons spin in either direction, the atom is magnetized. An example of a magnetized atom of iron is shown in figure below:



ANTIFERROMAGNETISM



Antiferromagnetic ordering

In materials that exhibit antiferromagnetism, the magnetic moments of atoms or molecules, usually related to the spins of electrons, align in a regular pattern with neighboring spins (on different sublattices) pointing in opposite directions. This is, like ferromagnetism andferrimagnetism, a manifestation of ordered magnetism. Generally, antiferromagnetic order may exist at sufficiently low temperatures, vanishing at and above a certain temperature, the Néel temperature (named after Louis Néel, who had first identified this type of magnetic ordering). Above the Néel temperature, the material is typically paramagnetic.

Geometric frustration

Unlike ferromagnetism, anti-ferromagnetic interactions can lead to multiple optimal states (ground states—states of minimal energy). In one dimension, the anti-ferromagnetic ground state is an alternating series of spins: up, down, up, down, etc. Yet in two dimensions, multiple ground states can occur.

Consider an equilateral triangle with three spins, one on each vertex. If each spin can take on only two values (up or down), there are $2^3 = 8$ possible states of the system, six of which are ground states! The two situations which are not ground states are when all three spins are up or are all down. In any of the other six states, there will be two favorable interactions and one unfavorable one. This illustrates frustration: the inability of the system to find a single ground state. This type of magnetic behavior has been found in minerals that have a crystal stacking structure such as a Kagome lattice or hexagonal lattice.

Antiferromagnetic materials

Antiferromagnetic materials occur commonly among transition metal compounds, especially oxides. An example is the heavy-fermion superconductor URu_2Si_2. Better known examples include hematite, metals such as chromium, alloys such as iron manganese (FeMn), and oxides such as nickel oxide (NiO). There are also numerous examples among high nuclearity metal clusters. Organic molecules can also exhibit antiferromagnetic coupling under rare circumstances, as seen in radicals such as 5-dehydro-m-xylylene.

Antiferromagnets can couple to ferromagnets, for instance, through a mechanism known as exchange bias, in which the ferromagnetic film is either grown upon the antiferromagnet or annealed in an aligning magnetic field, causing the surface atoms of the ferromagnet to align with the surface atoms of the antiferromagnet. This provides the ability to "pin" the orientation of a ferromagnetic film, which provides one of the main uses in so-called spin valves, which are the basis of magnetic sensors including modern hard drive read heads. The temperature at or above which an antiferromagnetic layer loses its ability to "pin" the magnetization direction of an adjacent ferromagnetic layer is called the blocking temperature of that layer and is usually lower than the Néel temperature.

Other properties

Antiferromagnetism plays a crucial role in giant magnetoresistance, as had been discovered in 1988 by the Nobel prize winners Albert Fertand Peter Grünberg (awarded in 2007).

There are also examples of disordered materials (such as iron phosphate glasses) that become antiferromagnetic below their Néel temperature. These disordered networks 'frustrate' the antiparallelism of adjacent spins; i.e. it is not possible to construct a network where each spin is surrounded by opposite neighbour spins. It can only be determined that the average correlation of neighbour spins is antiferromagnetic. This type of magnetism is sometimes called speromagnetism.

NÉEL THEORY

The theoretical basis for how ancient magnetic fields might be preserved was established over fifty years ago with the work of Nobel prize winner Louis Néel (1949, 1955). In the introduction to this chapter, we suggested that the mechanism which controls the approach to magnetic equilibrium is relaxation time. In the sheep analogy this would be the frequency of fence jumping. We defined relaxation time by Equation 4.11 in Chapter 4, sometimes called the Néel equation, which relates τ to volume v, the anisotropy constant (K) and absolute temperature (T).

Relaxation time is controlled by the competition between anisotropy energy Kv and thermal energy, so will be constant at a given temperature with constant Kv. Iso-τs of equal relaxation time are curves in v - K space. Figure 7.2b shows the family of curves with τs ranging from ~100 seconds to the age of the Earth. The inset to Figure 7.2b illustrates the effect of temperature on the iso-τs, which move up and to the right with increasing temperature. This behavior gives us a clue as to how a rise in temperature could change a “blocked” remanence at 0°C (273K) (one that is stable for long periods of time) to an unblocked one. In fact, Figure 7.2b (and the inset) suggests two other ways of manipulating the approach to equilibrium besides temperature: by changing the time span of observation and by changing grain volume. Each of these mechanisms represents a different mode of remanence acquisition (thermal, viscous, and chemical remanences respectively). Naturally acquired remanences are generally referred to as natural remanent magnetizations or NRMs. In this chapter we will introduce these and other forms of NRM and how they are acquired. We will also introduce useful unnatural remanences where appropriate.

In the “sheep in the rain” scenario, jumping over the fence into the sun would occur more frequently than jumping into the rain. It is also true that the energy barrier for magnetic particles to flip into the direction of the applied field H requires less energy than to flip the other way, so relaxation time must also be a function of the applied field. This tendency is reflected in the more general form of the Néel equation:

$$\tau = \frac{1}{C} \exp \frac{[Kv]}{[kT]} [1 - \frac{H}{H_c}]^2. \quad (7.1)$$

In this chapter we are concerned mainly with magnetic remanences acquired in the presence of the Earth’s magnetic field, which is tiny compared to the coercivity of the minerals in question and so we can neglect the effect of H on τ in the next few sections.

In Equation 7.1, the product Kv is an energy barrier to the rotation of m and we will call it the blocking energy. High blocking energies will promote more stable magnetizations. We learned in Chapter 4 that K for uniaxial shape anisotropy, K_u, is related to the coercivity H_c (the field required to flip the magnetization) by:

$$H_c = \frac{2K_u}{\mu_o M_s},$$

where M_s is the saturation magnetization. Substituting for K_u in Equation 4.11 from Chapter 4 we get:

$$\tau = \frac{1}{C} \exp \frac{[\mu_o H_c M_s v]}{[2kT]}, \quad (7.2)$$

where M_s is itself a strong function of temperature. We can see from Equation 7.2 that relaxation time is a function of magnetization, as well as volume, coercivity and temperature, properties that we will return to later in the chapter and in future chapters through out the course.

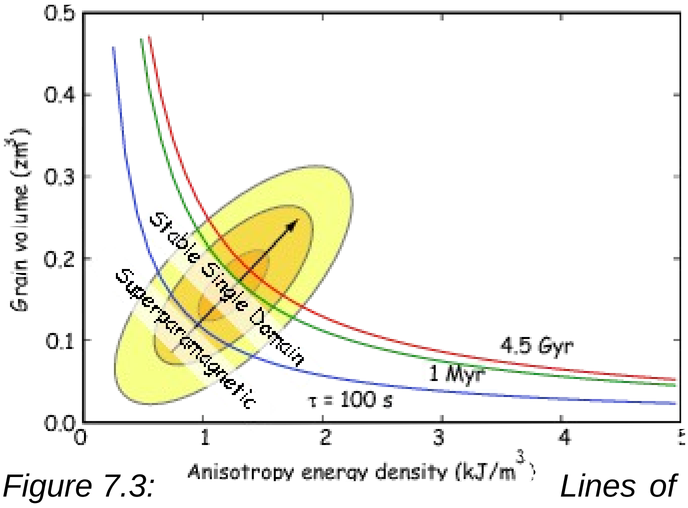
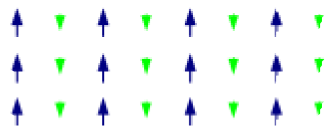


Figure 7.3: Lines of equal blocking energy in plot of grain volume, v, against the anisotropy energy density, K. Lines of equal blocking energy (product Kv) are also lines of equal relaxation time, τ, at a given temperature (here assumed to be room temperature). Contours are for a hypothetical population of magnetic grains. Grains with short τ plot toward the lower left. Grains with long τ plot toward the upper right; superparamagnetic grains with τ < 100s plot to the left or below the "superparamagnetic line" when τ ≃ 100s . Stable single domain grains with τ >100s plot above or to right of superparamagnetic line.

It is instructive to plot distributions of grains on the v - K diagrams as shown in Figure 7.3b. By definition, superparamagnetic grains are those grains whose remanence relaxes quickly. A convenient critical relaxation time, for purposes of laboratory experiments may be taken as ~100 s. Effective paleomagnetic recorders must have relaxation times on the order of geological time. So it might be more appropriate to choose τs of the age of the Earth (4.5 Gyr) as the relevant relaxation for geological time scales.

FERRIMAGNETISM



Ferrimagnetic ordering

In physics, a ferrimagnetic material is one in which the magnetic moments of the atoms on different sub lattices are opposed, as in antiferromagnetism; however, in ferrimagnetic materials, the opposing moments are unequal and a spontaneous magnetization remains. This happens when the sub lattices consist of different materials or ions (such as Fe^{2+} and Fe^{3+}).

Ferrimagnetic materials are like ferromagnets in that they hold a spontaneous magnetization below the Curie temperature, and show no magnetic order (are paramagnetic) above this temperature. However, there is sometimes a temperature *below* the Curie temperature at which the two sub lattices have equal moments, resulting in a net magnetic moment of zero; this is called the *magnetization compensation point*. This compensation point is observed easily in garnets and rare earth - transition metal alloys (RE-TM). Furthermore, ferrimagnets may also exhibit an *angular momentum compensation point* at which the angular momentum of the magnetic sub lattices is compensated. This compensation point is a crucial point for achieving high speed magnetization reversal in magnetic memory devices .

Ferrimagnetism is exhibited by ferrites and magnetic garnets. The oldest-known magnetic substance, magnetite (iron (II, III) oxide; Fe_3O_4), is a ferrimagnet; it was originally classified as a ferromagnet before Néel's discovery of ferrimagnetism and antiferromagnetism in 1948.

Some ferrimagnetic materials are YIG (yttrium iron garnet) and ferrites composed of iron oxides and other elements such as aluminum, cobalt, nickel, manganese and zinc.

Properties

Ferrimagnetic materials have high resistivity and have anisotropic properties. The anisotropy is actually induced by an external applied field. When this applied field aligns with the magnetic dipoles it causes a net magnetic dipole moment and causes the magnetic dipoles to precess at a frequency controlled by the applied field, called *Larmor* or *precession frequency*. As a particular example, a microwave signal circularly polarized in the same direction as this precession strongly interacts with the magnetic dipole moments; when it is polarized in the opposite direction the interaction is very low. When the interaction is strong, the microwave signal can pass through the material. This directional property is used in the construction of microwave devices like isolators, circulators and gyrators. Ferrimagnetic materials are also used to produce optical insulators and circulators.

FERRITE

Ferrites are a class of chemical compounds with the formula AB_2O_4, where A and B represent various metal cations, usually including iron. These magnetic ceramic materials are used to make permanent magnets, ferrite cores for transformers, and in various other high tech applications.

Ferrites are a class of spinels, materials that adopt a crystal motif consisting of cubic close-packed (FCC) oxides (O^{2-}) with A cations occupying one eighth of the tetrahedral holes and B cations occupying half of the octahedral holes. The magnetic material known as "ZnFe" has the deceptively simple formula $ZnFe_2O_4$, with Fe^{3+} occupying the octahedral sites and half of the tetrahedral sites. The remaining tetrahedral sites in this spinel are occupied by Zn^{2+}.

Properties

Ferrites are usually non-conductive ferrimagnetic ceramic compounds derived from iron oxides such as hematite (Fe_2O_3) or magnetite (Fe_3O_4) as well as oxides of other metals. Ferrites are, like most other ceramics, hard and brittle. In terms of the magnetic properties, ferrites are often classified as "soft" and "hard" which refers to their low or high coercivity of their magnetism, respectively.

Soft ferrites

Ferrites that are used in transformer or electromagnetic cores contain nickel, zinc, and/or manganese compounds. They have a low coercivity and are called soft ferrites. The low coercivity means the material's magnetization can easily reverse direction without dissipating much energy (hysteresis losses), while the material's high resistivity prevents eddy currents in the core, another source of energy loss. Because of their comparatively low losses at high frequencies, they are extensively used in the cores of switched-mode power supply (SMPS) and RF transformers and inductors. A common ferrite, chemical symbol MnZn, is composed of the oxides of manganese and zinc.

The most common ferrites are manganese-zinc (MnZn, with the formula $Mn_aZn_{(1-a)}Fe_2O_4$) and nickel-zinc (NiZn, with the formula $Ni_aZn_{(1-a)}Fe_2O_4$). NiZn ferrites exhibit higher resistivity than MnZn, and are therefore more suitable for frequencies above 1 MHz. MnZn have in comparison higher permeability and saturation induction.

Hard ferrites

In contrast, permanent ferrite magnets are made of hard ferrites, which have a high coercivity and high remanence after magnetization. These are composed of iron and barium or strontium oxides. In a magnetically saturated state they conduct magnetic flux well and have a high magnetic permeability. This enables these so-called *ceramic magnets* to store stronger magnetic fields than iron itself. They are cheap, and are widely used in household products such as refrigerator magnets. The maximum magnetic field B is about 0.35 tesla and the magnetic field strength H is about 30 to 160 kiloampere turns per meter (400 to 2000 oersteds). (Hill 2006)

Production

Ferrites are produced by heating an intimate mixture of powdered precursors pressed into a mold. During the heating process, calcination of carbonates occurs:

$$MCO_3 \rightarrow MO + CO_2$$

The oxides of barium and strontium are typically supplied as their carbonates, $BaCO_3$ or $SrCO_3$. The resulting mixture of oxides undergoes sintering. Sintering is a high temperature process similar to the firing of ceramic ware.

Afterwards the cooled product is milled to particles smaller than 2 µm, small enough that each particle consists of a single Weiss domain. Next the powder is pressed into a shape, dried, and re-sintered. The shaping may be performed in an external magnetic field, in order to achieve a preferred orientation of the particles (anisotropy).

Small and geometrically easy shapes may be produced with dry pressing. However, in such a process small particles may agglomerate and lead to poorer magnetic properties compared to the wet pressing process. Direct calcination and sintering without re-milling is possible as well but leads to poor magnetic properties.

Electromagnets are pre-sintered as well (pre-reaction), milled and pressed. However, the sintering takes place in a specific atmosphere, for instance one with an oxygen shortage. The chemical composition and especially the structure vary strongly between the precursor and the sintered product.

To allow efficient stacking of product in the furnace during sintering and prevent parts sticking together, many manufacturers separate ware using Ceramic Powder Separator Sheets. These sheets are available in various materials such as alumina, zirconia and magnesia. They are also available in fine medium and coarse particle sizes. By matching the material and particle size to the ware being sintered, surface damage and contamination can be reduced while maximizing furnace loading.

Uses

Ferrite cores are used in electronic inductors, transformers, and electromagnets where the high electrical resistance of the ferrite leads to very low eddy current losses. They are commonly seen as a lump in a computer cable, called a ferrite bead, which helps to prevent high frequency electrical noise (radio frequency interference) from exiting or entering the equipment.

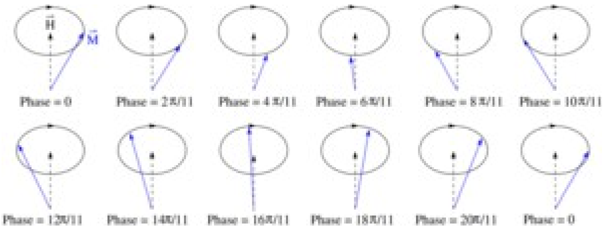
Early computer memories stored data in the residual magnetic fields of hard ferrite cores, which were assembled into arrays of *core memory*. Ferrite powders are used in the coatings of magnetic recording tapes. One such type of material is iron (III) oxide.

Ferrite particles are also used as a component of radar-absorbing materials or coatings used in stealth aircraft and in the expensive absorption tiles lining the rooms used for electromagnetic compatibility measurements.

It is a common magnetic material for electromagnetic instrument pickups, because of price and relatively high output. However, such pickups lack certain sonic qualities found in other pickups, such as those that use Alnico alloys or more sophisticated magnets.

SPIN WAVES

Spin waves are propagating disturbances in the ordering of magnetic materials. These low-lying collective excitations occur in magnetic lattices with continuous symmetry. From the equivalent quasiparticle point of view, spin waves are known as magnons, which are boson modes of the spin lattice that correspond roughly to the phonon excitations of the nuclear lattice. As temperature is increased, the thermal excitation of spin waves reduces a ferromagnet's spontaneous magnetization. The energies of spin waves are typically only μeV in keeping with typical Curie points at room temperature and below.



An illustration of the precession of a spin wave about an applied magnetic field with a wavevector that is eleven times the lattice constant.

POSSIBLE QUESTIONS

PART-B (10 Marks)

1. Define polymers. Explain the following: i) Conductive polymers and (ii) Supra molecular structures.
2. Define polymers. Explain the following: i) Nanocrystals, ii) Dendritic molecules & iii) Micelles
3. Define polymers. Explain the various significant properties of polymers.
4. Discuss about the photo fragmentation.
5. Explain in detail about Metal Nano particles.
6. Explain the face centred nano particles. Describe the size dependent properties of semiconducting nanoparticle.
7. Explain the formation and characterization of polymers.
8. Explain the size dependent properties of different nanomaterials. Describe the size dependent properties of semiconducting nanoparticles.
9. What do you mean by nanoscience? Explain metal nanoparticles along with surface structure.
10. What do you mean by single crystal? Describe optical properties of metal nanoparticles.

11 What are some of the polymers that you encounter every day? Describe their physical properties.

KARPAGAM ACADEMY OF HIGHER EDUCATION,COIMBATORE-21
DEPARTMENT OF PHYSICS
CLASS: I M. Sc. PHYSICS
CONDENSED MATTER PHYSICS (18PHP101)
UNIT -IV
MULIPLE CHOICE QUESTIONS

QUESTIONS	OPTION 1	OPTION 2	OPTION 3	OPTION 4
In Nanobiotechnology, size of nanomaterials is _____	dred billio	n billiont	ne billiont	nty billio
Bucky balls are made up of ______.	nickel.	DNA.	RNA.	carbon
_________________technology is used in making m	ano desig	no fabricat	Microassay	ue enginee
Which of the following is NOT a potential applicatio	A chip ass	c devices a	nsity optic	xtile indus
The art and science of etching, writing or printing at	NEMS.	o lithogra	o fabricati	no paltcini
What are the approaches used in making nano system	Top down.	Bottom up	oth a and	ither a nor
Ceramic powders find application in _________.	pigments.	abrasives.	catalysts.	ll the abov
Nano powders are defined as powders having an aver	100	1000	10	1
Which of the following are 1-D nano systems?	ds, Cylind	Cylinders,	nders, Pris	linders, wi
Which techniques is mostly used for the synthesis of	pic crystal	Top up.	ottom dow	icroscopi
Nanomembranes have a pore size of ______nm.	1-10.	10-100.	0.1-1.	100-1000.
Silicon or polymer devices that perform non-electron	icrosystem	anosystem	sensors.	nart system
Mention the nanomaterial used in the remediation of	tanium oxi	anoprobe	omembra	odium ions
The study that involves the behavior, manipulation a	nanoarray.	nocapillar	nanofluids.	anofringes
The concentration at which surfactants begin to form	icelle conc	icelle conc	icelle con	lecule con
Compounds that lower the surface tension of a liquid	detergents.	surfactants	tting agen	soaps.
Nanoemulsion are oil-in-water emulsion with mean d	50-100 nm	00-500 nm	50-100 nm	00-1000 nm
Machanics and Electronics that are on the nanoscale	MEMS.	NEMS.	MEM.	NEM.
Asemiconductor whose excitons are confined in all th	qubit.	bucky ball.	uantum do	dot.
Which of the following are applications of quantum	and fluor	rug deliver	r other dru	ll the abov
Structures that have a thickness or diameter constrain	nano tubes	nano wires	ano crystal	ucky balls
Which one of the following is used in making nanow	ZnO.	TiO	eavy metal	Hydrogen.
Nanoparticles that are used as pharmaceutical deliver	nanocapsule	anocarrier	nanotubes.	nanocubes
Which of the following can be used as nanocarriers?	nes, quant	lles, dendri	icrocapsul	ll the abov
Self-assembled nanosystems used for targeting subce	anoparticle	oassemble	anocarrier	nanofilms.
Nanopores are made up of _______.	carbon.	titanium.	titanium.	silicon.
Nanopore sequencing is a method for determining the	RNA.	DNA.	cDNA.	Template.
Fullerences are _______.	nanomater	n based ca	polymers.	dendrimers
Nano particles in biomedical application are _______	no capsul	ano sphere	oth a and	ither a nor
Nanodevices use _______ to move linearly by rotatio	ATP	electricity.	otor protei	no machin
Two dimensional protein crystals that might provide	proteins.	otein array	d protein a	r protein a
Which metal is used with nanoparticles for antibiotic	Gold.	Titanium	Zinc.	Silver.
Which of the following is NOT an application of full	ic photovo	ntioxidant	Additives.	Imaging
Expand CNT.	per Nano T	on Nano T	ll Nano Tu	stal Nano t
Which of the following is NOT a type of fullerene?	ano onion	Nano tubes	ucky balls	uantum do
_____ is essentially miniaturized in laboratories that	Chip	Biochip	Nanochip	Biosensors
Which one of the following is NOT an important mic	m depositi	Bonding	Etching.	beam lith
Which one of the following is NOT a nano fabrication	nduced nan	beam lith	tolithogra	sed lithog
Which one of the following is NOT a nano fabricatio	ection lith	ection lith	y lithogra	t lithograp
Which one of the following is NOT a nanofabricatio	onolayer li	id phototyp	nduced na	m depositi
Which one of the following is NOT used as a materia	Silicon	Metal	Iron	Glass

_____ have been used as quantum dots and as chemi	cro particl	Metals.	ano particl	ogical parti
What is the application of Nanobiotechnology?	o scale stu	oscopic fa	logical acti	ll the abov
Strongest element in the earth is_______.	Silicon	Metal	Iron	Diamond
Fullerence are______________.	made up	buckyballs	w carbon t	ll the abov
Nanoshells are__________.	articles usd	glass nar	oated nano	ted nanop
Bottom up approach is building starts __________.	naller fron	larger to sn	equally.	orizontally
Nano lithography means ______.	ano writin	ano drawin	writing.	drawing.
The temperature used in chemical deposition method	110	100	1100	90
Nanonose is __________.	o biosens	nanocell.	anodevice	biosensor.
Self-assemble layers are __________ structures.	1D	3D	0D	2D
Polymers have thermal conductivities in the range of	< 1	1 to 10	10 to 100	>100
Polymers have thermal expansion coefficients in the	0.5-15	5 to 25	25 to 50	50 to 400
Thermal conductivity in polymers increases with ___	se in crysta	se in cryst	Either	None
The following material can be used for filling in sand	Polymers	Cement	Wood	All
The word ‘polymer’ meant for material made from _	ingle entit	wo entitie	ltiple entit	Any entity
One of characteristic properties of polymer material _	mperature	echanical	gh elongati	ow hardne
Polymers are ___________ in nature.	Organic	Inorganic	th (a) and	None
These polymers can not be recycled:	hermoplas	Thermoset	Elastomers	ll polyme
In general, strongest polymer group is	hermoplas	Thermoset	Elastomers	ll polyme
Strong covalent bonds exists between polymer chains	hermoplas	Thermoset	Elastomers	ll polyme
Following is the unique to polymeric materials:	Elasticity	iscoelastici	Plasticity	None
Elastic deformation in polymers is due to _________	st of molec	of molecu	g of mole	of Covalen
Kevlar is commercial name for ___________ .	lass fiber	arbon fibe	ramid fibe	Cermets
Repeatable unit of polymers	isomer	copolymer	mopolym	mer
Composite materials are	prove tem	roved opti	ofter matr	atrix to ob
Which one are inorganic materials	gical mate	als and cer	plastics	wood
Graphite is a good conductor of electricity due to the	pair of elec	alence ele	cations	anions
Graphite cannot be classified as __________.	ducting sc	etwork sol	valent sol	ionic solid

ANSWER

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carbon
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Diamond
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UNIT-V

SYLLABUS

Superconductivity Sources of superconductivity – The Meissner effect – Thermodynamics of superconducting transitions – Origin of energy gap – London equations –London Penteration depth – Type I and Type II Sueprconductors - Coherence length – BCS theory – Flux quantization – Theory of DC and AC Josephesen effect – Potential applications of superconductivity.

SUPERCONDUCTIVITY SOURCES OF SUPERCONDUCTIVITY

What is a superconductor?

Superconductors are materials that conduct electricity with no resistance. This means that, unlike the more familiar conductors such as copper or steel, a superconductor can carry a current indefinitely without losing any energy. They also have several other very important properties, such as the fact that no magnetic field can exist within a superconductor.

Superconductors already have drastically changed the world of medicine with the advent of MRI machines, which have meant a reduction in exploratory surgery. Power utilities, electronics companies, the military, transportation, and theoretical physics have all benefited strongly from the discovery of these materials.

A brief history of superconductors

The first discovery of a superconductive material took place in 1911 when a Dutch scientist named Heike Kammerlingh Onnes, who was also the first person to liquefy helium, and reached temperatures as low as 1.7 kelvin (K).

In the 1960s, two unrelated discoveries made closely together ushered in a new era in which practical superconducting devices were developed and commercialized: one was the discrovery of NbTi superconductor, which provided the first material for the practical manufacture of superconducting wire and shaped components; the second was the Josephson junction, which continues to provide the basis for a variety of unique electronic devices.

Unique electrical, magnetic properties

Superconducting materials have unique electrical and magnetic properties. They have no electrical resistance, so current will flow through them forever, and they are diamagnetic, meaning that a magnet held above them will levitate.

These properties can be exploited to create powerful magnets for medical imaging, make power lines that transport electricity efficiently or make efficient power generators.

However, there are no known materials that are superconductors at room temperature and pressure. All known superconducting materials have to be cooled to extreme temperatures and/or compressed at high pressure.

“At ambient pressure, the highest temperature at which a material becomes superconducting is 134 K (-218 °F).

THE MEISSNER EFFECT

When a material makes the transition from the normal to superconductingstate, it actively excludes magnetic fields from its interior; this is called the Meissner effect.

This constraint to zero magnetic field inside a superconductor is distinct from the perfect diamagnetism which would arise from its zero electrical resistance. Zero resistance would imply that if you tried to magnetize a superconductor, current loops would be generated to exactly cancel the imposed field (Lenz's law). But if the material already had a steady magnetic field through it when it was cooled trough the superconducting transition, the magnetic field would be expected to remain. If there were no change in the applied magnetic field, there would be no generated voltage (Faraday's law) to drive currents, even in a perfect conductor. Hence the active When a material makes the transition from the normal to superconducting state, it actively excludes magnetic fields from its interior; this is called the Meissner effect.

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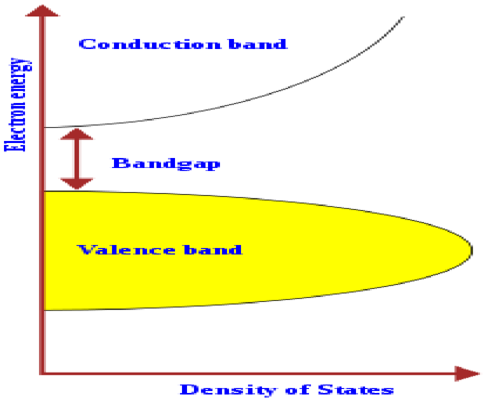
One of the theoretical explanations of the Meissner effect comes from theLondon equation. It shows that the magnetic field decays exponentially inside the superconductor over a distance of 20-40 nm

THERMODYNAMICS OF SUPERCONDUCTING TRANSITIONS

Thermodynamics of the superconducting transition The variation of specific heat with temperature is often a good probe of phase transitions in matter. Historically, it is Ehrenfest who first classified phase transitions based on the variation of the thermodynamic free energy with some state variable such as temperature. The order of a transition was defined as the lowest derivative of free energy (with respect to some variable) that was discontinuous at the transition. If the first derivative of free energy were discontinuous (such as the case of a solid-liquid transition where the density is discontinuous), then the transition is called first order. In the case of ferromagnetic transition of Fe for example, the susceptibility (i.e., the second derivative of free energy with field) is discontinuous and one would classify this as a second order phase transition. However, there are many cases in nature where rather than discontinuous jumps in thermodynamic variables, there is a divergence such as in the heat capacity of a superconductor. Over the decades, changes in these criteria have been proposed to accommodate such cases. The modern classification of phase transitions is based on the existence or lack thereof of a latent heat. If a phase transition involves a latent heat, i.e., the substance absorbs or releases heat without a change in temperature, then it is called a order phase transition. In the absence of a latent heat, the phase transition is a order transition. Landau gave a theory of order phase transitions and its application to superconductors will be discussed later in these lectures. The variation of the enthalpy in the vicinity of a first order phase transition. The variation of the enthalpy in the vicinity of a non-first order phase transition. The figure shows the schematic variation of enthalpy in the case of a transition involving a latent heat. For a type I superconductor, in general, there is an entropy change at the transition temperature (and therefore a latent heat) making the transition order. However, in zero magnetic field, the entropy change is zero and hence the transition is order. In the normal state, the electronic contribution to the heat capacity is linear in temperature, as explained in a previous chapter. The heat capacity exhibits a jump at and at lower temperatures, it falls with an exponential temperature dependence. The exponential dependence is due to the opening up of a gap in the excitation spectrum. Signatures of a gap are seen in various other properties such as thermal conductivity, current-voltage characteristics, etc. Variation of X with temperature for a normal metal & a Supercoducting 1. Entropy 2. Heat capacity 3. Internal Energy 4. Free Energy The accompanying figures contrast the variation with temperature of some basic thermodynamic quantities such as the entropy S, the internal energy U, the heat capacity C and the Helmholtz free energy F. Basic thermodynamics and

ORIGIN OF ENERGY GAP

Every solid has its own characteristic energy-band structure. This variation in band structure is responsible for the wide range of electrical characteristics observed in various materials. In semiconductors and insulators, electrons are confined to a number of bands of energy, and forbidden from other regions. The term "band gap" refers to the energy difference between the top of the valence band and the bottom of the conduction band. Electrons are able to jump from one band to another. However, in order for an electron to jump from a valence band to a conduction band, it requires a specific minimum amount of energy for the transition. The required energy differs with different materials. Electrons can gain enough energy to jump to the conduction band by absorbing either a phonon (heat) or a photon (light).



A semiconductor is a material with a small but non-zero band gap that behaves as an insulator at absolute zero but allows thermal excitation of electrons into its conduction band at temperatures that are below its melting point. In contrast, a material with a large band gap is an insulator. In conductors, the valence and conduction bands may overlap, so they may not have a band gap.

The conductivity of intrinsic semiconductors is strongly dependent on the band gap. The only available charge carriers for conduction are the electrons that have enough thermal energy to be excited across the band gap and the electron holesthat are left off when such an excitation occurs.

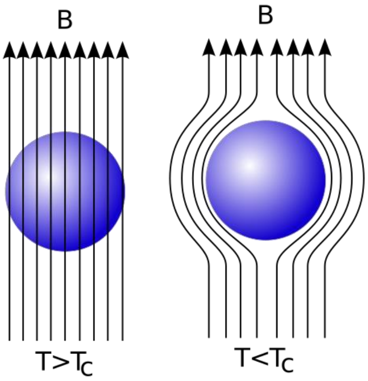
Photovoltaic cells

The Shockley–Queisser limit gives the maximum possible efficiency of a single-junction solar cell under un-concentrated sunlight, as a function of the semiconductor band gap. If the band gap is too high, most daylight photons cannot be absorbed; if it is too low, then most photons have much more energy than necessary to excite electrons across the band gap, and the rest is wasted. The semiconductors commonly used in commercial solar cells have band gaps near the peak of this curve, for example silicon (1.1eV) or CdTe (1.5eV). The Shockley–Queisser limit has been exceeded experimentally by combining materials with different band gap energies to make tandem solar cells.

The optical band gap (see below) determines what portion of the solar spectrum aphotovoltaic cell absorbs.[5] A semiconductor will not absorb photons of energy less than the band gap; and the energy of the electron-hole pair produced by a photon is equal to the bandgap energy. A luminescent solar converter uses a luminescentmedium to downconvert photons with energies above the band gap to photon energies closer to the band gap of the semiconductor comprising the solar cell.[6]

LONDON EQUATIONS

The London equations, developed by brothers Fritzand Heinz London in 1935,[1] relate current toelectromagnetic fields in and around a superconductor. Arguably the simplest meaningful description of superconducting phenomena, they form the genesis of almost any modern introductory text on the subject. A major triumph of the equations is their ability to explain the Meissner effect,[5] wherein a material exponentially expels all internal magnetic fields as it crosses the superconducting threshold.



TYPE I SUEPRCONDUCTORS

In Type I superconductors transition from normal state to superconducting state occurs instantly i.e. at exactly it's critical/transition temperature TcTc:
also this type of superconductors "repel" magnetic field lines fully, i.e. no magnetic field line could penetrate through in this type of superconductors:

TYPE II SUEPRCONDUCTORS

In Type II Type II superconductors transition from a normal state to a superconducting state occurs "slowly" i.e. as you decrease temperature from it's critical temperature superconducting properties increase

BCS THEORY

BCS theory or Bardeen–Cooper–Schrieffer theory (named after John Bardeen, Leon Cooper, and John Robert Schrieffer) is the first microscopic theory of superconductivity since Heike Kamerlingh Onnes's 1911 discovery. The theory describes superconductivity as a microscopic effect caused by a condensation of Cooper pairs into a boson-like state. The theory is also used in nuclear physics to describe the pairing interaction between nucleons in an atomic nucleus.

BCS theory starts from the assumption that there is some attraction between electrons, which can overcome the Coulomb repulsion. In most materials (in low temperature superconductors), this attraction is brought about indirectly by the coupling of electrons to the crystal lattice (as explained above). However, the results of BCS theory do not depend on the origin of the attractive interaction. For instance, Cooper pairs have been observed in ultracold gases of fermions where a homogeneous magnetic field has been tuned to their Feshbach resonance. The original results of BCS (discussed below) described an s-wave superconducting state, which is the rule among low-temperature superconductors but is not realized in many unconventional superconductors such as the d-wave high-temperature superconductors.

Extensions of BCS theory exist to describe these other cases, although they are insufficient to completely describe the observed features of high-temperature superconductivity.

BCS is able to give an approximation for the quantum-mechanical many-body state of the system of (attractively interacting) electrons inside the metal. This state is now known as the BCS state. In the normal state of a metal, electrons move independently, whereas in the BCS state, they are bound into Cooper pairs by the attractive interaction. The BCS formalism is based on the reduced potential for the electrons' attraction. Within this potential, a variational ansatz for the wave function is proposed. This ansatz was later shown to be exact in the dense limit of pairs. Note that the continuous crossover between the dilute and dense regimes of attracting pairs of fermions is still an open problem, which now attracts a lot of attention within the field of ultracold gases.

FLUX QUANTIZATION

If a charged particle travels in a field free region that surrounds another region, in which there is trapped magnetic flux F, then upon completing a closed loop the particle's wave function will acquire an additional phase factor $\exp\left(\frac{ie\Phi}{\hbar c}\right)$. But the wave function must be single valued at any point in space. This can be accomplished if the magnetic flux F is quantized. We need

$$\frac{e\Phi}{\hbar c} = 2\pi n, \quad n = 0, \pm1, \pm2, \cdots.$$

This quantization of the magnetic flux is observed in superconductors. Superconductivity is theorized to be due to a special correlation between pairs of electrons that extends over the whole body of the superconductor. When a Type I superconductor is placed in a magnetic field and cooled below its critical temperature, it excludes all magnetic flux from its interior. This is called the **Meissner effect**. If there is a "hole" in the superconductor, then flux can be trapped in this hole. The flux trapped in the hole must be quantized. It has been experimentally verified that the trapped flux is quantized in units of $\Phi = \frac{2\pi\hbar c}{2e}$, thus verifying that the charge carriers in superconductors are indeed correlated electron pairs of charge 2e.

Magnetic monopoles

In Maxwell's equations magnetic charges do not appear. We have $\nabla \cdot \boldsymbol{B} = 0$. No magnetic charges have been confirmed to exist. Quantum mechanics does not require that magnetic charges exist, but it unambiguously requires the quantization of magnetic monopoles and predicts the unit of magnetic charge if they should ever be found.

Assume that magnetic monopoles exist and that a magnetic monopole is located at the origin. Then $\vec{\nabla} \cdot \boldsymbol{B} = 4\pi\rho_M$ and $\boldsymbol{B} = \frac{e_M}{r^2}\hat{\boldsymbol{r}}$.

We have

$$\boldsymbol{B} = \vec{\nabla} \times \boldsymbol{A} = \hat{\boldsymbol{r}}\left[\frac{1}{r\sin\theta}\frac{\partial}{\partial\theta}\left(A_\phi \sin\theta\right) - \frac{\partial A_\theta}{\partial\phi}\right].$$

A possible solution is A=e_M(1-cosq)/(rsinq) in the f-direction. But **A** is singular on the negative z-axis at q=p. If we consider **A** just a device for obtaining **B**, then we can construct a pair of vector potentials

$$\boldsymbol{A}_1 = \left[\frac{e_M(1-\cos\theta)}{r\sin\theta}\right]\hat{\boldsymbol{\phi}}, \qquad (\theta < \pi - \varepsilon), \qquad \text{and } \boldsymbol{A}_2 = -\left[\frac{e_M(1+\cos\theta)}{r\sin\theta}\right]\hat{\boldsymbol{\phi}}, \qquad (\theta > \varepsilon),$$

which together yield the correct **B** everywhere. **A**$_1$ can be used everywhere except inside a cone defined by q=p-e around the negativez-axis, and **A**$_2$ can be used everywhere except inside a cone defined by q=e around the positive z-axis. In the overlap region $\varepsilon \le \theta \le \pi - \varepsilon$ either **A**$_1$ or **A**$_2$ can be used. The two potentials lead to the same magnetic field and are therefore related to each other by a gauge transformation.

$$A_2 - A_1 = -\left(\frac{2e_M}{r\sin\theta}\right)\hat{\boldsymbol{\phi}} = \vec{\nabla}f, \qquad \vec{\nabla}f = \hat{\boldsymbol{r}}\frac{\partial f}{\partial r} + \hat{\boldsymbol{\theta}}\frac{1}{r}\frac{\partial f}{\partial\theta} + \hat{\boldsymbol{\phi}}\frac{1}{r\sin\theta}\frac{\partial f}{\partial\phi}, \qquad f = -2e_M\phi$$

The wave function of a charged particle depends on the particular gauge used. In the overlap region we have $\psi_2 = \exp\left(\frac{-2iee_M\phi}{\hbar c}\right)\psi_1.$ Here e is the particle's electric charge. The wave function must be single valued. As we increase the azimuthal angle f from 0 to 2p, the wave function must return to its original value. This is only possible if $\frac{2ee_M}{\hbar c} = n, \quad n = 0, \pm1, \pm2, \cdots.$ We therefore find that e_M must be quantized in units of $\frac{\hbar c}{2|e|} = \frac{137}{2}|e|.$ The smallest magnetic charge possible is $\frac{\hbar c}{2|e|}.$

POTENTIAL APPLICATIONS OF SUPERCONDUCTIVITY.

Magnetic Resonance Imaging (MRI) and Nuclear Magnetic Resonance (NMR)

The biggest application for superconductivity is in producing the large-volume, stable, and high-intensity magnetic fields required for MRI and NMR. This represents a multi-billion-US$ market for companies such as Oxford Instruments andSiemens. The magnets typically use low-temperature superconductors (LTS) because high-temperature superconductor sare not yet cheap enough to cost-effectively deliver the high, stable, and large-volume fields required, notwithstanding the need to cool LTS instruments to liquid helium temperatures. Superconductors are also used in high field scientific magnets.

Particle accelerators and magnetic fusion devices

Particle accelerators such as the Large Hadron Collider can include many high field electromagnets requiring large quantities of LTS. To construct the LHC magnets required more than 28 percent of the world’s niobium-titanium wire production for five years, with large quantities of NbTi also used in the magnets for the LHC’s huge experiment detectors.

A small number of magnetic fusion devices have used SC coils. The current construction of ITER has required unprecedented amounts of LTS (e.g. 500 tonnes, causing a 7 fold increase in the world's annual production capacity).

Electric power transmission

Essen, Germany has the world's longest superconducting power cable in production at 1 kilometer. It is a 10 kV liquid nitrogen cooled cable. The cable is smaller than an equivalent 110 kV regular cable and the lower voltage has the additional benefit of smaller transformers.[4]

High-temperature superconductivity (HTS)

The commercial applications so far for high temperature superconductors (HTS) have been limited.

HTS require only liquid nitrogen, not liquid helium, to cool to superconducting temperatures. However, the problem with HTS technology is that the currently known high temperature superconductors are brittle ceramics which are expensive to manufacture and not easily formed into wires or other useful shapes.[5] Therefore, the applications for HTS have been where it has some other intrinsic advantage, e.g. in

- low thermal loss current leads for LTS devices (low thermal conductivity),
- RF and microwave filters (low resistance to RF), and
- increasingly in specialist scientific magnets, particularly where size and electricity consumption are critical (while HTS wire is much more expensive than LTS in these applications, this can be offset by the relative cost and convenience of cooling); the ability to ramp field is desired (the higher and wider range of HTS's operating temperature means faster changes in field can be managed); or cryogen free operation is desired (LTS generally requires liquid helium that is becoming more scarce and expensive).

HTS-based systems

HTS has application in scientific and industrial magnets, including use in NMR and MRI systems. Commercial systems are now available in each category.[6]

Also one intrinsic attribute of HTS is that it can withstand much higher magnetic fields than LTS, so HTS at liquid helium temperatures are being explored for very high-field inserts inside LTS magnets.

Promising future industrial and commercial HTS applications include Induction heaters, transformers, fault current limiters power storage, motors and generators, fusion reactors and magnetic levitation devices.

Early applications will be where the benefit of smaller size, lower weight or the ability to rapidly switch current (fault current limiters) outweighs the added cost. Longer-term as conductor price falls HTS systems should be competitive in a much wider range of applications on energy efficiency grounds alone. (For a relatively technical and US-centric view of state of play of HTS technology in power systems and the development status of Generation 2 conductor see Superconductivity for Electric Systems 2008 US DOE Annual Peer Review.)

Holbrook Superconductor Project

The Holbrook Superconductor Project is a project to design and build the world's first production superconductingtransmission power cable. The cable was commissioned in late June 2008. The suburban Long Island electrical substation is fed by about 600-meter-long underground cable system consists of about 99 miles of high-temperature superconductor wiremanufactured by American Superconductor, installed underground and chilled with liquid nitrogen greatly reducing the costly right-of-way required to deliver additional power.[7]

Tres Amigas Project

American Superconductor was chosen for The Tres Amigas Project, the United States' first renewable energy market hub.[8]The Tres Amigas renewable energy market hub will be a multi-mile, triangular electricity pathway of superconductor electricity pipelines capable of transferring and balancing many gigawatts of power between three U.S. power grids (the Eastern Interconnection, the Western Interconnection and the Texas Interconnection). Unlike traditional powerlines, it will transfer power as DC instead of AC current. It will be located in Clovis, New Mexico.

Magnesium diboride

Magnesium diboride is a much cheaper superconductor than either BSCCO or YBCO in terms of cost per current-carrying capacity per length (cost/(kA*m)), in the same ballpark as LTS, and on this basis many manufactured wires are already cheaper than copper. Furthermore, MgB_2 superconducts at temperatures higher than LTS (its critical temperature is 39 K, compared with less than 10 K for NbTi and 18.3 K for Nb_3Sn), introducing the possibility of using it at 10-20 K in cryogen-free magnets or perhaps eventually in liquid hydrogen.[citation needed] However MgB_2 is limited in the magnetic field it can tolerate at these higher temperatures, so further research is required to demonstrate its competitiveness in higher field applications.

Trapped field magnets

Exposing superconducting materials to a brief magnetic field can trap the field for use in machines such as generators. In some applications they could replace traditional permanent magnets.

POSSIBLE QUESTIONS

PART-B (10 Marks)

1. Describe the superconductivity
2. Describe the Meissner Effect
3. Describe Thermodynamic of Superconductivity.
4. Explain about London Equation
5. Explain Coherence Length Theory
6. What is BCS Theory.
7. Explain the working Potential Applications of Superconducitivity
8. Explain the working Josephesen Effect

KARPAGAM ACADEMY OF HIGHER EDUCATION,COIMBATORE-21
DEPARTMENT OF PHYSICS

CLASS: I M. Sc. PHYSICS

CONDENSED MATTER PHYSICS (18PHP101)
UNIT -V
MULIPLE CHOICE QUESTIONS

QUESTIONS	OPTION 1	OPTION 2	OPTION 3	OPTION 4
TEM is ________.	n Electron	lectron M	Electron M	lectricalM
SLMS are ______.	Light Mod	Light Mi	g Light M	Light Micr
Expand MRFM.	nance For	esonance	Resonance	e of the ab
_______ microscope has been used to build nano sized s	TEM.	AFM.	STM.	SEM.
_____ lithographic pattern a resist by physically deform	icro impri	ano imprin	and nano i	acro impri
____ is the art and science of etching, writing or printin	nolithogra	cal lithogr	ay lithogra	lithograp
_____ includes various methods of modifying semicond	cal lithogr	olithograp	ay lithogra	ro lithogra
_______ is used during the fabrication of leading etch s	ay lithogra	olithograp	cal lithogr	-lithograp
_____ lithography and its variants such as step and flash	icro impri	ano impri	utral partic	xtreme UV
Atomic force microscopic nanolithography is a chemo-n	electron.	atomic.	tomic forc	omic partic
______ lithography is used to transfer a used generated	Photo.	soft	Film	Bonding
encompasses three different techniques which are all ba	m depositi	Bonding.	tolithogra	ftlithograp
_______ consists of the formation of micron thick films	m depositi	Bonding.	Etching.	ftlithograp
QFM is____________.	ntact force	force mic	ontact mic	e of the ab
______ is considered as the most expensive micromecha	Etching	-off techni	Lithograph	Masking
Types of lithography:	tolithogra	ay lithogra	am lithogr	l of the abo
In X-ray lithography, the X-ray absorber is usually:	Silver	Gold	Aluminum	e of the ab
The electron gun is used in lithography because it is ___	nexpensiv	Accurate	equire hig	e of the ab
Types of etching are _________	Vet isotrop	et anisotro	Dry	l of the abo
Etching is always anisotropic if the material is________	Crystalline	lycrystalli	Amorphou	e of the ab
_________ is the etching through chemical or physical	sotropic et	isotropic e	Dry etching	e of the ab
_________ is used for metals that are hard to etch:	-off techni	ysical/che	al sputter	cal plasma
Lithography is used for:	st layers on	Cutting too	ng electric	e of the ab
Types of photoresist:	Positive	Negative	a & b	e of the ab
_________ is projecting electron beam directing on pho	am lithogr	ight emitti	tron beam	Radar bean
Used for removing desired areas of the photo resist from	LIGA	Lithograph	Etching	e of the ab
Methods of dry etching are:	al sputter	cal plasma	emical/ph	l of the abo
One of the most used kinds of lasers in microfabrication	Excimer	mond mill	micromach	e of the ab
_________ process is also called spark erosion	asonic mac	wder blast	ft lithogra	o discharg
_________ is the most used in silicon micromachining:	micromac	o-Discharg	lk machini	wder Blasti
_________ method removes material through erosive ac	mond mill	ft lithogra	o discharg	wder blasti
the full wafer thickness range is:	0—200 m	0—400 n	0—200 n	80—200 s
What limits the resolving power of a light microscope?	dye that is	ject's ima	light used	o magnify
When biologists wish to study the internal ultrastructure	electron m	ht microsc	n electroni	oth A and

ANSWER

n Electron Microscope.
Light Modulators.
nance Force Microscopy.
STM.
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cal lithography.
ano imprint.
tomic force.
Photo.
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Accurate
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ry etching
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st layers on the substrate
a & b
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Etching
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lk machining.
o discharge machining
30—200 ms
light used to illuminate the specimen
n electronic microscope.