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Energy Bands Theory in Solids Energy levels The angular momentum of an electrons is always quantized and is integral multiple of. Thus the electrons can have certain orbital radii. The electrons in these orbits have only a certain values of energy. These certain values of energy of electrons in an atom are called the energy levels of the atom. The energy levels of an isolated single atom are will defined usually represented by series of horizontal lines. When the two identical atoms are close to each other, their electrons move under the influence electromagnetic fields of two atoms. As the result, each energy level split into two levels, one higher and other lower than the corresponding level of the isolated atom. Energy Band When the numbers of atoms are brought together, as in a crystal, they interact with one another. As the result, each energy level splits up into several sub-levels. A group of such energy sub-levels are called an energy band. The number of energy sub-levels in a band is equal to the number of atoms in a crystal. The energy band in a crystal corresponds to the energy level in an atom. And an electron in a crystal can have an energy that falls within one of these bands. Forbidden Bands The energy bands are separated by gaps in which there is no energy level. Such energy gaps are called forbidden bands. The electron may jump from one energy band to another by acquiring energy equal to the energy of forbidden energy gap. Valence Bands The electrons in the outermost shell of an atom are called valance electrons. Therefore, the energy band occupied by valance electrons is called the valance band. The valance band may be either completely filled or partially filled with the electrons but can never be empty. Conduction Band The energy band next to the valance band is called the conduction band. The valance and conduction bands are separated by forbidden energy gaps. The conduction band may be empty or partially filled. The electrons in the conduction band can drift freely in the materials and are called free or conduction electrons. The width of forbidden energy gap between valance and conduction band decide whether a material is a conductor, insulator or a semiconductor. Distinction between Conductors, Insulators and Semiconductors on the basis of Band Theory of Solids Conductors All metals are good conductors of electricity and their resistivity is of the order of. In case of conductors, there is no forbidden energy gap between the valance and the conduction band. The valance band and conduction band are partially filled at room temperature. So the electrons can easily jump from valance band to the conduction band. Due to this reason, the current can easily pass through conductors. Insulators The insulators have the very large value of resistivity which is of the order of. In case of insulators, the valance band is completely filled and the conduction band is empty. The energy gap between the valance and conduction band is very large. Thus, no electron can jump from valence band to conduction band. As there are no free electrons in insulator, hence no current can pass through insulators. Semiconductors The materials which have intermediate values of resistivity of the order of called semiconductor materials. The energy gap between the valance and conduction band is very small. A semiconductor is a material that is between conductors and insulators in its ability to conduct electrical current. A semiconductor in its pure intrinsic state is neither a good conductor nor a good insulator. The most common single-element semiconductors are silicon,germanium, and carbon. Compound semiconductors such as gallium arsenide are also commonly used. Intrinsic Semiconductors A pure semiconductor is known as intrinsic semiconductor. The most common examples of intrinsic semiconducting materials are silicon. Each atom of silicon has four valance electrons. Moreover each atom of silicon is surrounded by four atoms. A silicon Si atom with its four valence electrons shares an electron with each of its four neighbors to form covalent bond. This effectively creates eight shared valence electrons for each atom and produces a state of chemical stability. The semiconducting materials have negative temperature coefficient of resistivity. At low temperatures, the valence band is completely filled and conduction band is completely empty. Thus the semiconducting materials behave like insulator at low temperatures. At comparatively higher temperature, the electrons in valance band acquire sufficient energy to jump in conduction band. As the temperature increases, the probability of the electrons to jump from valance to conduction band increases.

Therefore, the conductivity of semiconductors increases with increase in temperature. At absolute zero, the intrinsic semiconducting materials behaves like insulators because they have no free electrons. The electrons jump from valance band to conduction band by absorbing the thermal energy. As the result, the conductivity of semiconductor increases with increase in temperature. Extrinsic Semiconductors The semiconductors doped with some impurity are called extrinsic semiconductors. The conductivity of silicon and germanium can be drastically increased by the controlled addition of impurities to the intrinsic pure semiconductive material. This process, called doping, increases the number of current carriers electrons or holes. The two categories of impurities are n-type and p-type. N-Type Semiconductor To increase the number of conduction-band electrons in intrinsic silicon, pentavalent impurity atoms e. Each pentavalent atom antimony, in this case forms covalent bonds with four adjacent silicon atoms. This extra electron becomes a conduction electron because it is not attached to any atom. Because the pentavalent atom gives up an electron, it is often called a donor atom. The number of conduction electrons can be carefully controlled by the number of impurity atoms added to the silicon. Majority and Minority Carriers in N-Type Semiconductor In an n-type semiconducting material, most of the current carriers are electrons. So, the electrons are called the majority carriers in n-type material. Although the majority of current carriers in n-type material are electrons, there are also a few holes that are created when electron-hole pairs are thermally generated. Holes in an n-type material are called minority carriers. P-Type Semiconductor To increase the number of holes in intrinsic silicon, trivalent impurity atoms e. Because the trivalent atom can take an electron, it is often referred to as an acceptor atom. The number of holes can be carefully controlled by the number of trivalent impurity atoms added to the silicon. Majority and Minority Carriers in P-Type Semiconductor In a p-type semiconducting material, most of the current carriers are holes. Holes can be thought of as positive charges because the absence of an electron leaves a net positive charge on the atom. The holes are the majority carriers in p-type material. Although the majority of current carriers in p-type material are holes, there are also a few free electrons that are created when electron-hole pairs are thermally generated. Electrons in p-type material are the minority carriers. The p region has many holes majority carriers from the impurity atoms and only a few thermally generated free electrons minority carriers. The n region has many free electrons majority carriers from the impurity atoms and only a few thermally generated holes minority carriers. When the PN-junction is formed, the n region loses free electrons as they diffuse across the junction. This creates a layer of positive charges pentavalent ions near the junction. As the electrons move across the junction, the p region loses holes as the electrons and holes combine. This creates a layer of negative charges trivalent ions near the junction. These two layers of positive and negative charges form the depletion region. The term depletion refers to the fact that the region near the PN-junction is depleted of charge carriers electrons and holes due to diffusion across the junction. After the initial surge of free electrons across the PN-junction, the depletion region has expanded to a point where equilibrium is established and there is no further diffusion of electrons across the junction. In other words, the depletion region acts as a barrier to the further movement of electrons across the junction. Barrier Potential In the depletion region there are many positive charges and many negative charges on opposite sides of the PN-junction. The forces between the opposite charges form a "field of forces" called an electric field. This electric field is a barrier to the free electrons in the n region, and energy must be expended to move an electron through the electric field. That is, external energy must be applied to get the electrons to move across the barrier of the electric field in the depletion region. The potential difference of the electric field across the depletion region is the amount of voltage required to move electrons through the electric field. This potential difference is called the barrier potential and is expressed in volts. The typical barrier potential is approximately 0. Energy Diagrams of the PN-Junction and Depletion Region The valence and conduction bands in an n-type material are at slightly lower energy levels than the valence and conduction bands in a p-type material. This is due to differences in the atomic characteristics of the pentavalent and the trivalent impurity atoms. The valence and conduction bands in the n region are at lower energy levels than those in the p region, but there is a significant amount of overlapping. The free electrons in the n region that occupy the upper part of the conduction band in terms of their energy can easily diffuse across the junction and temporarily become free electrons in the lower part of the p-region conduction band. After crossing the junction, the electrons quickly lose energy and fall into the holes in the p-region valence band as indicated in figure below: As the diffusion continues, the depletion region begins to form and the energy level of the n-region conduction band decreases.

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