28

SEMICONDUCTORS AND SEMICONDUCTING DEVICES

ENERGY BANDS IN SOLIDS

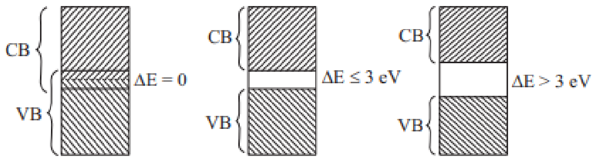
When two atoms come closer to form a stable structure, such that the separation between them tends to be lesser than their diameter (d), the energy states tend to overlap, which is forbidden by Pauli's exclusion principle.

Hence, they get modified and corresponding to each of the interaction energy states, two energy states are created: one slightly lower than the normal state which is called the bonding state and the other slightly higher than the normal state called the antibonding state

Quasi continuous distribution of energy states, which are though separate but practically in discriminable, is called energy band.

The process of interaction of energy states (and thereby energy band formation) starts from outer unfilled energy states and then proceeds to valence level. The band formed of unfilled energy levels is called conduction band and the one formed of filled valence levels is called valence band.

Classification of Solids as Conductors, Semiconductors and Insulators on the basis of Energy Bands

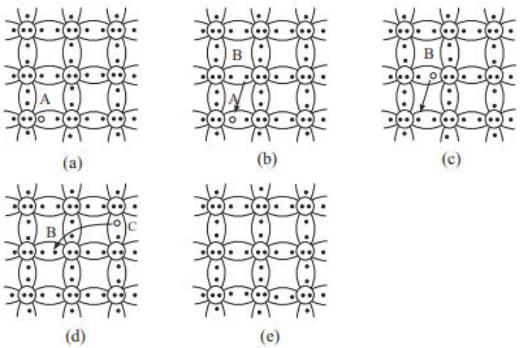


Conductor Semiconductor Insulator

INTRINSIC AND EXTRINSIC SEMICONDUCTORS

An Intrinsic Semiconductor

- Pure silicon and germanium are intrinsic semiconductors as the electrons in these elements are all tightly held in their crystalline structure, i.e., they do not have free electrons.
- When energy is added to pure silicon in the form of heat, say, it can cause a few electrons to break free of their bonds, leaving behind a hole in each case.
- These electrons move randomly in the crystal. These electrons and holes are called free carriers, and move to create electrical current
- when a free electron moves in a crystal because of thermal energy; its path deviates whenever it collides with a nucleus or other free electrons. This gives rise to a zig-zag or random motion, which is similar to that of a molecule in a gas



(a) (b) (c)
(d) (e)

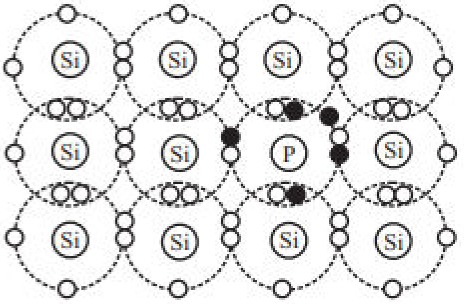
An Extrinsic Semiconductor

The process in which some atoms of a pure or intrinsic semiconductor are replaced by impurity atoms from their lattice-sites is called doping and the impurity so added is called dopant.

- Such doped semiconductors are called extrinsic semiconductors.

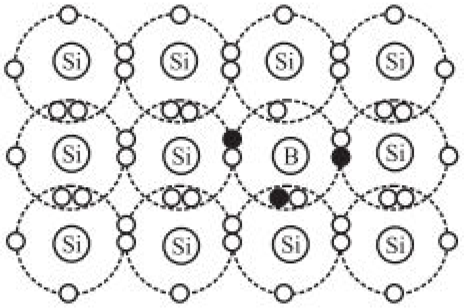
n-and p-type Semiconductors

n-type Semiconductor



When silicon (or germanium) is doped with a pentavalent (five electrons in the outermost orbit) atom like phosphorus, arsenic or antiomony, four electrons form covalent bonds with the four neighbouring silicon atoms, but the fifth (valence) electron remains unbound and is available for conduction when a silicon (or germanium) crystal is doped with a pentavalent element, it develops excess free electrons and is said to be an n-type semiconductor. Such impurities are known as donor impurities.

p-type Semiconductor



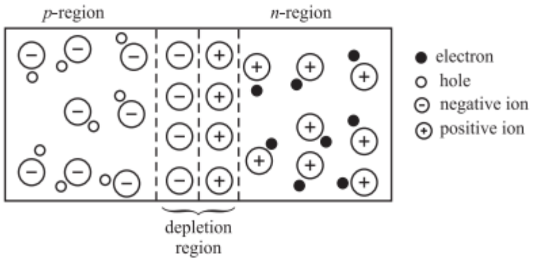
If silicon (or germanium) is doped with a trivalent (three electrons in the outermost shell) atom like boron, aluminium, gallium or indium, three valence electrons form covalent bonds with three silicon atoms and deficiency of one electron is created. This deficienty of electron is referred to as hole.

- Such a semiconductor is said to be a p-type semiconductor and the impurities are known as acceptor impurities.

A p-n JUNCTION

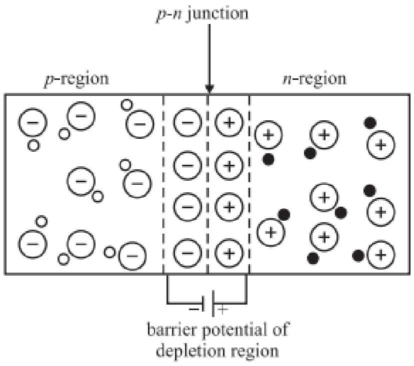
When a n-type material is placed in contact with a p-type material . The formation is known as p-n junction.

Formation of a p-n Junction

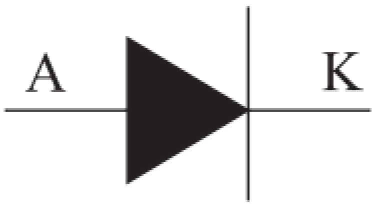


To form a p-n junction, the most convenient way is to introduce donor impurities on one side and acceptor impurities into the other side of a single semiconducting crystal,

after a few recombinations, a narrow region near the junction is depleted in mobile charge carriers. It is about 0.5 μm thick and is called the deplection region or space-charge region.



Due to accumulation of charges near the junction, an electric field is established. This gives rise to electrostatic potential, known as barrier potential. This barrier has polarities, as shown in Fig. 28.7. When there is no external electric field, this barrier prevents diffusion of charge carriers across the junction.

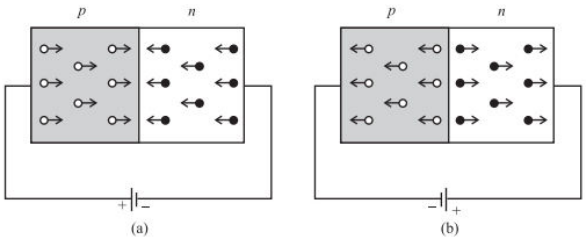


FORWARD AND REVERSE BIASED p-n JUNCTION

Biasing means application of voltage

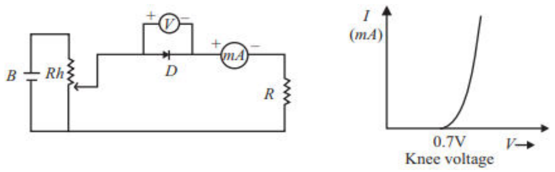
To make a p-n junction to conduct, we have to make electrons move from the n-type region to the p-type region and holes moving in the reverse direction. To do so, we have to overcome the potential barrier across the junction by connecting a battery to the two ends of the p-n junction diode

Positive terminal of the battery connected to the p-side and negative terminal of the battery connected to the n-side. This is called forward bias [Fig. 28.9(a)]. z Positive terminal of the battery connected to the n-side and negative terminal of the battery connected to the p-side. This is called reverse bias



CHARACTERISTICS OF p-n JUNCTION DIODES

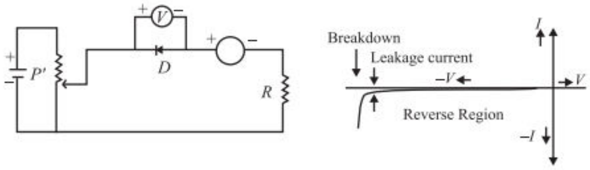
Forward Bias Characteristics



The forward voltage required to get the junction in conduction mode is called knee voltage. It is about 0.7 V for Si and 0.3 V for Ge p-n junction

As the applied voltage is increased beyond knee voltage, the current through the diode increases linearly.

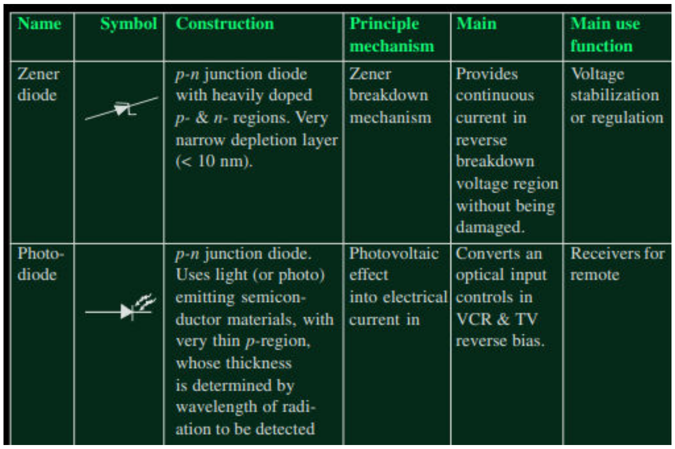
Reverse Bias Characteristics

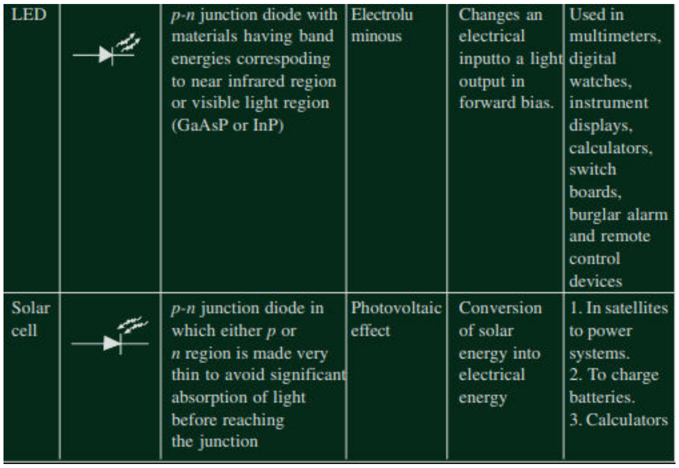


To draw reverse bias characteristics of a p-n junction

- (i) The terminals of the junction are reversed.
- (ii) (ii) Instead of milliammeter, microammeter (μ A) is used
- (iii) The unidirectional conducting property of a diode is used to convert ac voltage into dc voltage as a rectifier.
- (iv) Diodes are also used in adaptors to recharge batteries of cell phones, CDplayers, laptops, etc.
- (v) A device that uses batteries often contains a diode as it simply blocks any current from leaving the battery, if it is reverse biased. This protects the sensitive electronics in the device.

TYPES OF DIODES

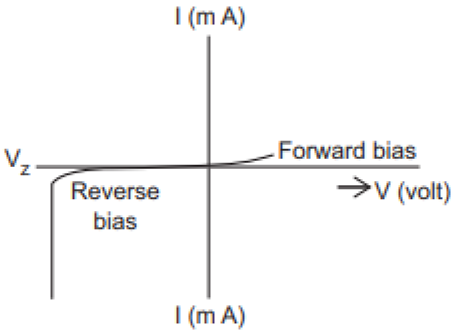




Name	Symbol	Construction	Principle mechanism	Main	Main use function
Zener diode		*p-n* junction diode with heavily doped *p-* & *n-* regions. Very narrow depletion layer (< 10 nm).	Zener breakdown mechanism	Provides continuous current in reverse breakdown voltage region without being damaged.	Voltage stabilization or regulation
Photo-diode		*p-n* junction diode. Uses light (or photo) emitting semicon-ductor materials, with very thin *p*-region, whose thickness is determined by wavelength of radi-ation to be detected	Photovoltaic effect into electrical current in	Converts an optical input controls in VCR & TV reverse bias.	Receivers for remote
LED		*p-n* junction diode with materials having band energies correspoding to near infrared region or visible light region (GaAsP or InP)	Electrolu minous	Changes an electrical inputto a light output in forward bias.	Used in multimeters, digital watches, instrument displays, calculators, switch boards, burglar alarm and remote control devices
Solar cell		*p-n* junction diode in which either *p* or *n* region is made very thin to avoid significant absorption of light before reaching the junction	Photovoltaic effect	Conversion of solar energy into electrical energy	1. In satellites to power systems. 2. To charge batteries. 3. Calculators

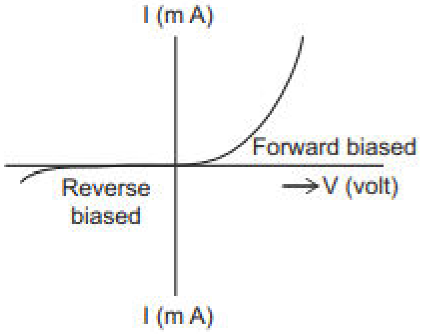
I–V Characteristics of Zener diode

Zener diode is fabricated by heavily doping both the p- and n-sides of the junction. Hence depletion layer formed is very thin 6 (< 10 m) − . And the electric field across the depletion layer is extremely high 6 –1 (5× 10 N C) ~ even for a small reverse bias voltage of 5 V.



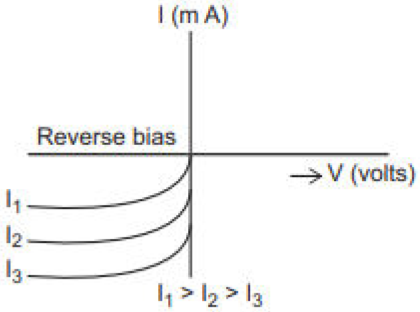
Characteristics of light-emitting diode

- In light-emitting diode (LED) when the forward current of diode is small the intensity of light emitted is small.
- As the forward current increases, the intensity of the emitted light increases and reaches a maximum value. Further increase in the forward current results in a decrease of light intensity.
- LEDs are biased such that the light emitting efficiency is maximum.



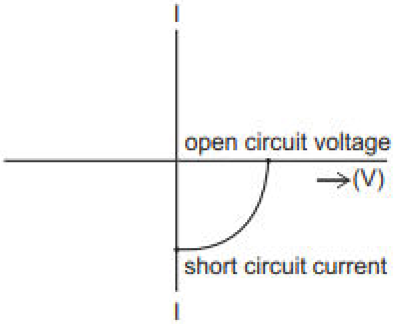
I-V Characteristics of Photo diode

- The photo diode is fabricated such that the generation of electron – hole pairs takes place in or near the depletion region in the diode. Due to the electric field of the junction, the electrons and holes are separated before they recombine.
- The direction of the electric field is such that the electrons reach the n-side and the holes reach the p-side. The electrons are collected on the n-side and the holes are collected on the p-side giving rise to an emf.
- When an external load is connected, the current flows. The magnitude of the photocurrent depends on the intensity of the incident light.



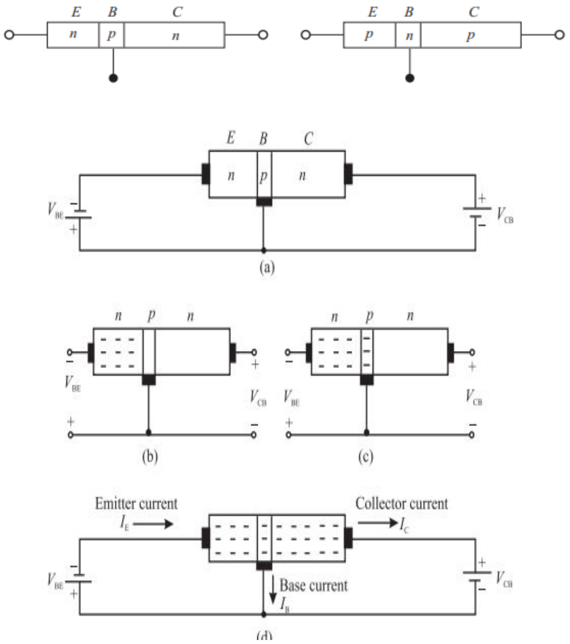
I-V Characteristics of Solar Cell

The generation of emf, when the light falls on a solar cell is due to the following three basic processes: generation, separation and collection. Generation of electron – hole pairs is due to the light (with hν> Eg) close to the junction. Separation of electrons and holes is due to the electric field of the depletion layer. Electrons are swept to the n-side and the holes to the p-side.



TRANSISTORS – pnp and npn

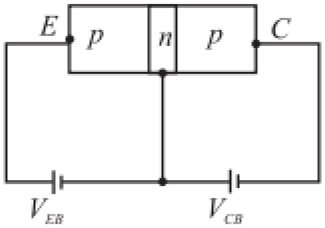
- A transistor is basically a silicon or germanium crystal containing three alternate regions of p and n-type semiconductors. These three regions are called emitter(E), base(B) and collector(C).
- The middle region is the base and the outer two regions are emitter and collector. the emitter and collector are of the same type (p or n) and collector is the largest of the three regions.



A np-n Transistor

$\alpha = \frac{I_c}{I_E}, \beta = \frac{I_c}{I_B}, \beta = \frac{\alpha}{1-\alpha}$

A p-n-p Transistor



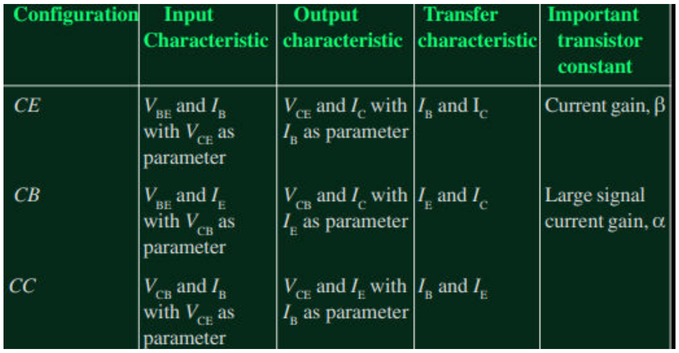
Transistor Configurations

A transistor is a two-port device; it can take an input and deliever an output. For both input and output, two terminals are needed. This can be done in a transistor by making one of the three terminals common

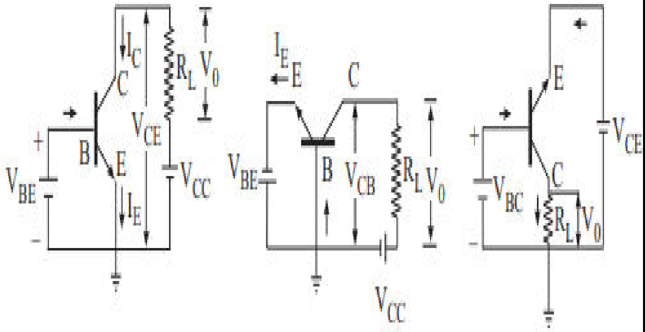
When emitter is common to both input and output circuits, we obtain common emitter (CE) configuration

When base is common to both input and output circuits, we obtain common base (CB) configuration

When collector is common to both input and output circuits, we have common collector (CC) configuration

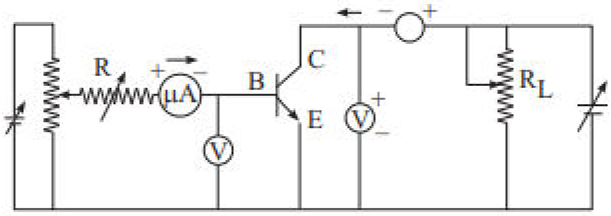


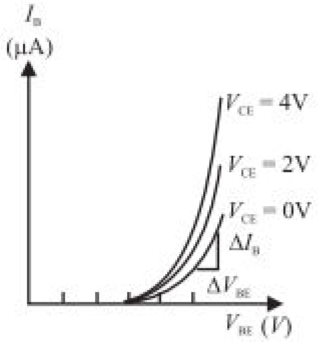
Configuration	Input Characteristic	Output characteristic	Transfer characteristic	Important transistor constant
CE	V_{BE} and I_B with V_{CE} as parameter	V_{CE} and I_C with I_B as parameter	I_B and I_C	Current gain, β
CB	V_{BE} and I_E with V_{CB} as parameter	V_{CB} and I_C with I_E as parameter	I_E and I_C	Large signal current gain, α
CC	V_{CB} and I_B with V_{CE} as parameter	V_{CE} and I_E with I_B as parameter	I_B and I_E	



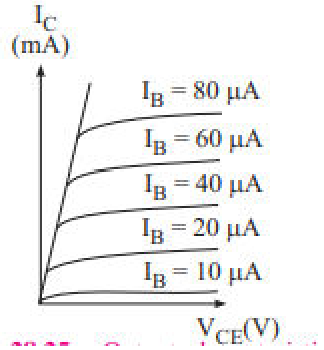
Transistor Characteristics

Common Emitter (CE) Configuration of a npn Transistor



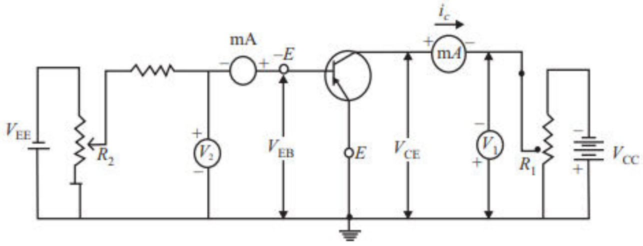


$$R_{ie} = \left.\frac{\Delta V_{BE}}{\Delta I_B}\right|_{V_{CE}}$$

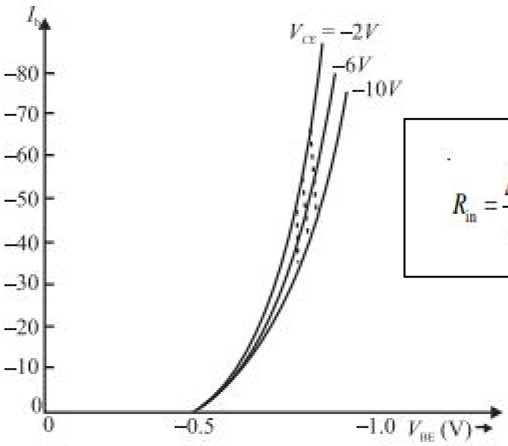


$$h_{oe} = \frac{\Delta I_C}{\Delta V_{CE}}$$

Common Emitter (CE) Configuration of a pnp Transistor

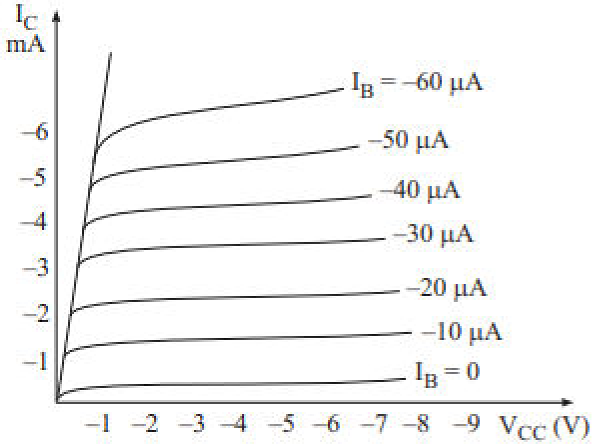


Input Characteristics



$$R_{in} = \frac{\Delta V_{BC}}{\Delta I_B}\bigg|_{V_{CE}} = \text{constant}$$

Output Characteristics



Check Yourself

1. For rectifying action we use
   A. Choke
   B. Transformer
   C. Condenser
   D. Diode
2. The saturation current in a diode can be increased by
   A. Lowering plate potential
   B. Raising plate potential
   C. Increasing cathode temperature
   D. Decreasing cathode temperature
3. Can a diode valve be used as an oscillator
   A. Yes
   B. No
   C. Some times with another diode
   D. None of the above
4. A semiconductor is the substance which contains
   A. A large number of free electron
   B. Only one electron in the outermost electron
   C. Only few electronat room temperature

   D. No free electon at o^{0}K and atomforms covalent bond with neighbouring bond

5. Which one of the followingis semiconductor
   A. Plastic
   B. Aluminium
   C. Wood
   D. Cesium

Stretch Yourself

1. Describe the most important characteristic of a p-n junction diodes.
2. Explain the formation of depletion region in a p-n junction diode.
3. Which charge carriers conduct forward current in a p-n junction diode?
4. Differentiate between (i) Forward bias and reverse bias (ii) Avalancehe and zener breakdown
5. Explain the working of p-n-p and n-p-n transistors

Hint to Check Yourself

1C 2C 3B 4D 5D