28/11/2020

PH301 - Engineering Optics End Sem Assignment

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Answers

Ans 1 Storage Capacities of DVD, Blue-Ray Disc and Dual Layer Blue-Ray Disc:

Device	Capacity
DVD	4.7GB
Blue-Ray Disc	25GB
Dual Layer Blue-Ray Disc	50GB

Data Storage in CDs and DVDs and Blue-Ray Discs:

(1) Data is stored digitally in the form of a series of ones and zeroes read by laser light reflected from disc.

(2) Strong reflections correspond to constructive interference and are chosen to represent zeroes.

(3) Weak reflections correspond to destructive interference and are chosen to represent ones

(4) A CD has multiple tracks and each track consists of a sequence of pits of varying length formed in a reflecting information layer.

(5) Pits appear as bumps to laser beam which shines on metallic layer through a clear plastic coating.

Reading data from a CD:

(1) When a CD is placed in a CD drive, it is spun at a very high speed (upto 500 rpm). Inside the drive, there is a laser beam and a photodetector. The laser beam is incident on the CD.

(2) As the disk rotates, laser beam reflects off the sequence of bumps and lower areas of the CD into a photodetector. The photodetector converts fluctuating reflected light intensity into an electrical string of zeroes and ones.

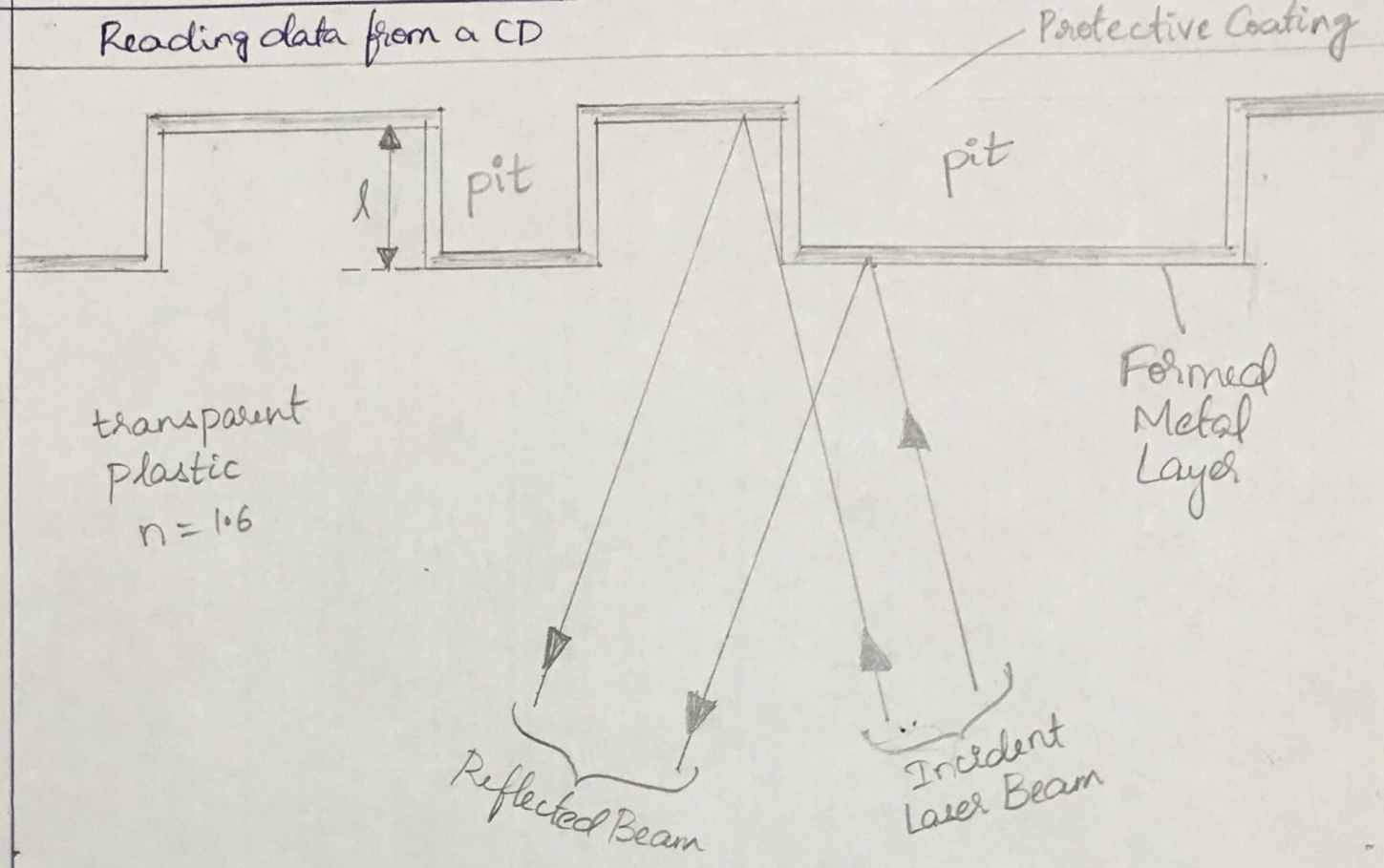
(3) Pit depth is generally equal to one-quarter of wavelength of laser beam.

(4) When the laser beam hits a rising or falling bump edge, part of the beam reflects from top of bump & part from lower adjacent area. This ensures destructive interference and very low intensity when reflected beams combine at the detector.

(5) Bump edges are read as ones.

(6) Flat bump tops & intervening flat plains are read as zeroes.

Reading data from a CD



Writing data to a CD

(1) The process of writing to a CD is called burning. It involves the creation of a pattern of pits and bumps over the surface of the CD. Since, the data must be accurately encoded on such a small scale, the burning process involves high precision.

(2) It incorporates a moving laser quite similar to a CD player which is known as 'Write Laser'. During burning process, as per data (binary values) the Write Laser bounces the light beam over the CD surface and creates a series of pits on it.

③ It is more powerful than Read Laser, since it has the capability to alter the surface of the CD instead of just bouncing the laser light off.

④ The beam striking the surface of the CD generates heat, which justifies the process being called burning.

⑤ If the light at a spot is completely absorbed, then that is data bit zero. In places where dye is unburned, the laser light reflects straight back again and 1 is stored. There this series of 0 and 1 is stored. Hence, this series of 0's and 1's stores required data on CD.

Reason for variation of storage capacities in CD, DVD, Blu-Ray Disc

All the three devices use light from laser diodes, for their spectral purity and ability to be focused precisely.

DVD uses light of 650nm wavelength (red) while CD uses 780nm. A shorter wavelength implies a smaller pit on disc surface. So, more data can be stored in a smaller region. Hence, DVD's have more storage capacity.

Blue-ray disc uses wavelength of 405nm (violet) so storage capacity is even higher, 25GB. Dual-layer disc has 50GB storage capacity.

Ans 2

(1) The given object is a fully-phase object with amplitude transmittance as $t(x,y) = \exp[i\phi(x,y)]$

(2) Phase Object is an object that is completely transparent but has an optical thickness which varies from point to point

(3) It introduces phase differences between disturbances which pass through different parts of it.

(4) Consequently, disturbances immediately behind object and in conjugate image plane, have same amplitude at all points but will show variations in phase from point to point.

(5) Since human eye is sensitive to intensity only and cannot detect changes of phase, phase contrast microscope must be used.

(6) Phase Contrast Microscopy is an adaptation of Light Microscopy and helps obtain a clear picture of living or unstained cells.

(7) Adaptors convert minute difference in phase changes in transmitted light due to refractive indices of all cell organelles into perceptible shades of grey.

(8) This allows organelles of living cell to become visible with fair contrast in them.

Principle of Phase Contrast

(1) Different wavelength of light rays detect differences in colours.

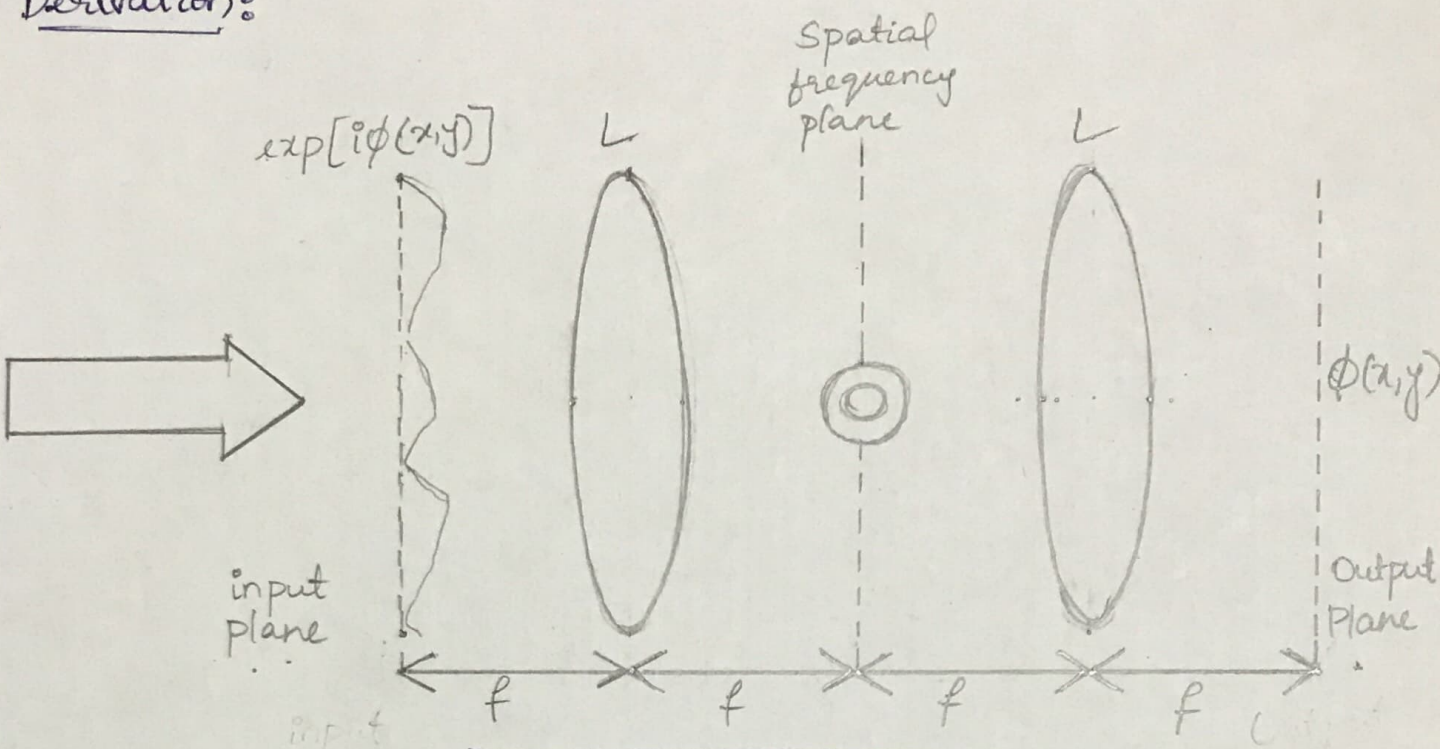
(2) Different shades of grey are distinguished to our eyes due to differences in amplitude of light rays.

(3) Phase Contrast Microscope converts invisible small phase changes caused by cell component into visible intensity changes.

(4) Phase changes are caused by biological material through which light ray passes. If a material is absorbent, it causes the ray to undergo a chance in amplitude, which is distinguished by our eyes.
Eg: Light passing through a window glass and without them.

(5) Phase contrast microscope is to convert undistinguishable phase change into distinguishable phase change in terms of variation of contrast, with the help of 2 adaptors – annular diaphragm and annular phase plate.

Derivation:



Arrangement for Phase Contrast

Consider a transparent object with amplitude transmittance,

$$t_A(x,y) = \exp[i\phi(x,y)]$$

Expanding $\exp[i\phi(x,y)]$

$$e^{i\phi(x,y)} = 1 + i\phi(x,y) - \frac{1}{2}\phi^2(x,y) - \frac{1}{6}i\phi^3(x,y) + \frac{1}{24}\phi^4(x,y) + \dots$$

For mathematical simplicity, assuming object has a magnitude of unity and finite extent of entrance exit pupils are neglected. Also, there is a necessary condition to achieve linearity between phase-shift and intensity. The condition is that the variable part of the object induced phase-shift $\Delta\phi(x,y)$, should be small compared with 2π radians.

Applying approximation to amplitude transmittance,

$$t_A(x,y) = e^{i\phi_0} e^{i\Delta\phi} \approx e^{i\phi_0}[1 + i\Delta\phi]$$

$$I \approx |1 + i\Delta\phi(x,y)|^2 \approx 1$$

Phase-changing plate consists of a glass substrate on which a small transparent dielectric dot is deposited. Dot is centered on optical axis in focal plane & has a thickness & index of refraction such that it should change phase of focused light by either $\pi/2$ radians or $3\pi/2$ radians relative to phase retardation of diffracted light. If phase retardation is by $\pi/2$ radians, intensity in image plane becomes.

$$I \approx |\exp[i(\pi/2)] + i\Delta\phi(x,y)|^2 = |i\{1 + \Delta\phi(x,y)\}|^2$$

$$\approx 1 + 2\Delta\phi(x,y)$$

Image intensity has become linearly related to variations of phase-shift $\Delta\phi(x,y)$. This situation is referred to as positive phase contrast. If the phase retardation is by $3\pi/2$ radians, intensity in image plane becomes,

$$I \approx |\exp[i(\tfrac{3\pi}{2})] + i\Delta\phi(x,y)|^2 = |-i\{1 - \Delta\phi(x,y)\}|^2 = 1 - 2\Delta\phi(x,y)$$

This case is referred to as negative phase contrast.
In this manner, we can observe a fully-phase object.
This procedure is called Phase Imaging

Ans 3 ① Laser Printer is an electrostatic digital printer invented by Gray Starkweather in 1969.

② It is a non-impact printer that utilizes a laser beam to produce an image on drum.

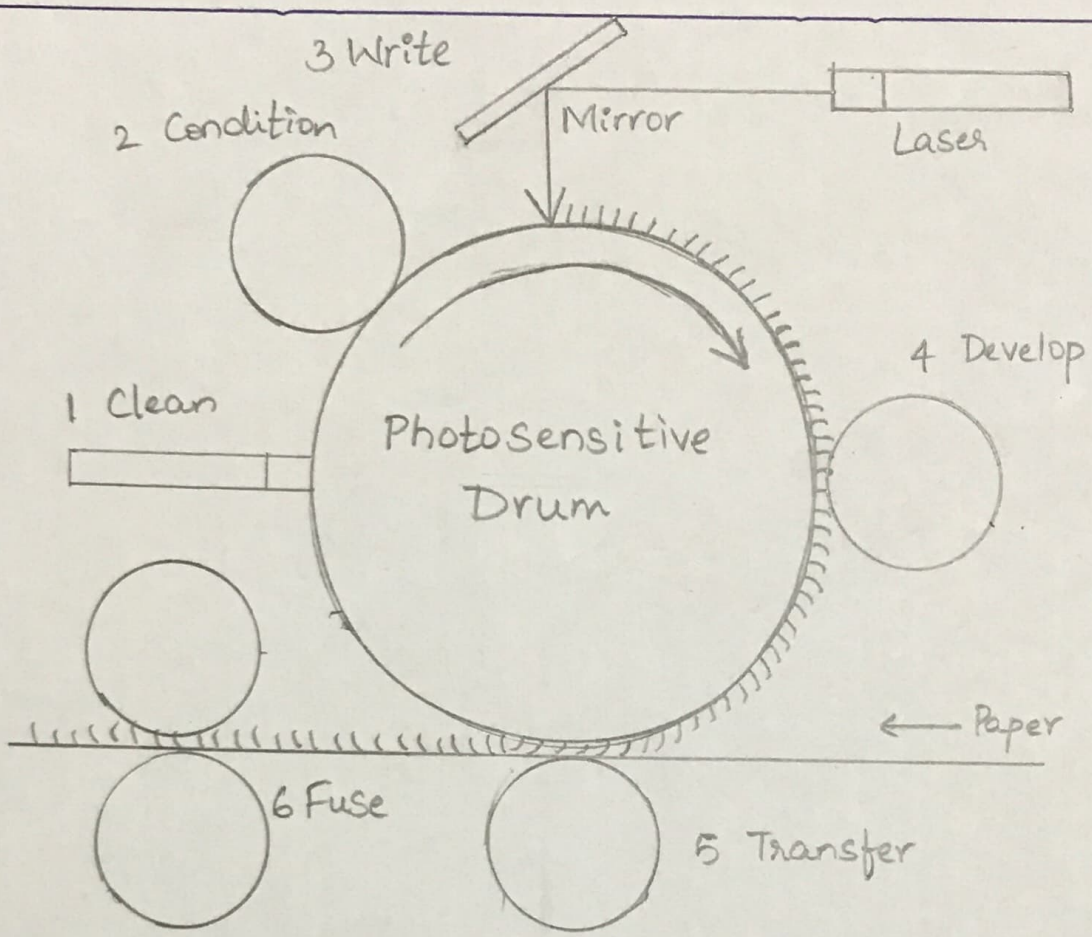
③ Commercially IBM introduced the first laser printer in 1975 to use it with mainframe computers.

④ In 1984, Hewlett-Packard(HP) revolutionized laser printing technology with its 1st ~~laserjet~~ LaserJet, a compact, fast & reliable printer.

Laser Printing Process

① Cleaning: Before a new page is printed, any remaining ink from previous page are cleared away. The drum is swept free with a rubber blade, and a florescent lamp removes any electrical charge remaining on the drum.

② Conditioning: Entire drum is uniformly charged by primary corona wire. This charge conditions the drum for next step.



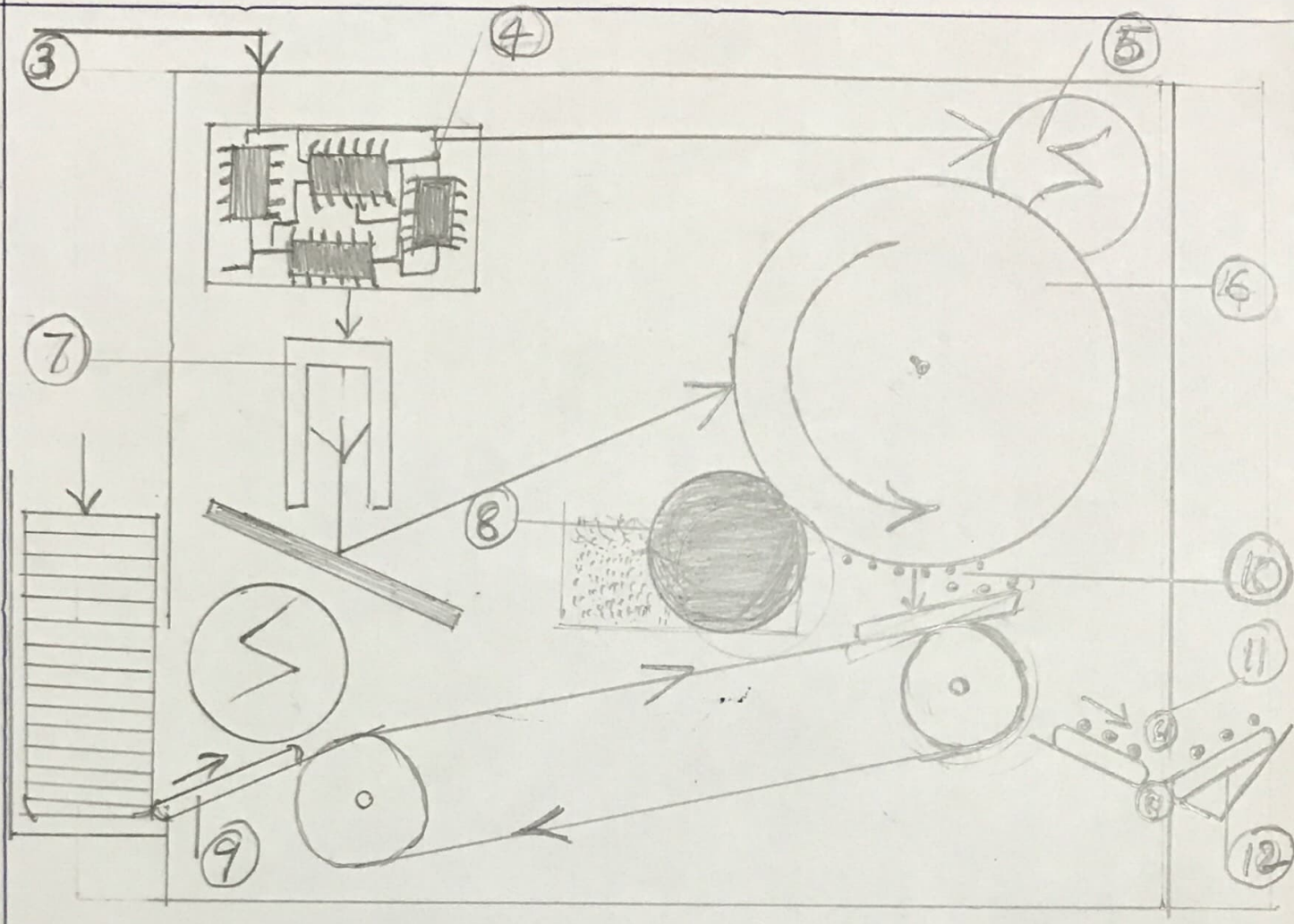
Laser Printing Process

(3) Millions of bytes (characters) of data stream into the printer from PC

(4) An electronic circuit in the printer (can be called a small computer) figures out how to print this data so it looks correct on the page.

(5) Electronic circuit activates corona wire (a high-voltage wire that gives a static electric charge to anything nearby)

(6) Corona wire charges up photoreceptor drum, so drum gains a +ve charge spread uniformly across its surface.



(7) Simultaneously, circuit activates laser to make it draw image of page onto the drum. Laser beam doesn't actually move, it bounces off a moving mirror that scans it over drum. Where, laser beam hits drum, it erases +ve charge & creates an area of -ve charge. Gradually, an image of entire page builds up on a drum: where page should be white, there are areas with a +ve charge, where page should be black, there are areas of -ve charge.

(8) An ink roller touching photoreceptor drum coats ~~with~~ it with tiny particles of powdered ink (toner). Toner has been given a +ve charge, so it sticks to parts of photoreceptor drum that have a -ve charge. No ink is attracted to parts of drum that have a +ve ~~drum~~ charge. An inked image of page builds up on drum.

(9) A sheet of paper ~~from~~ hopper on the other side of printer feeds up towards drum. As it moves along, ~~drum~~ paper is given a strong +ve charge by another corona wire.

(10) When paper moves near drum, its +ve charge attracts negatively charged toner particles. Image is transferred from drum onto paper but, for the moment, toner particles are just resting lightly on paper's surface.

(11) Inked paper passes through 2 hot rollers (fuser unit). Heat & pressure from rollers fuse the toner particles permanently into fibres of paper.

(12) Printout emerges from side of the copier. Thanks to the fuser unit, paper is still warm. It is literally hot off the press!

Ans 4 ① Liquid Crystals (LCs) are a state of matter which has properties between those of conventional liquids and those of solid crystals. For instance, a liquid crystal may flow like a liquid, but its molecules may be oriented in a crystal-like way.

② There are many different types of liquid crystal phases, which can be distinguished by their different optical properties (such as textures).

③ The contrasting areas in the textures correspond to domains where the liquid-crystal molecules are oriented in different directions. Within a domain, however, the molecules are well ordered.

④ LCs have 2 melting points. At the first melting point, the solid crystal melts into a cloudy liquid and at the second melting point, the cloudiness disappears leaving behind a liquid. In their ~~cloudy~~ cloudy liquid form, liquid crystals possess the ability to scatter light, reflect circularly polarized light, the ability to rotate the polarization direction of light. Due to these properties, LCs are used in flat panel electronic displays

One such application is ~~an~~ the Liquid Crystal Display (LCD)
To make an LCD, you need to take 2 polarized glass pieces. The glass which doesn't have a polarized film on it must be rubbed with a special polymer which creates microscopic grooves in the surface. It must also be noted that the grooves are in same direction as the polarizing film. Then, all you need to do is to add a coating of nematic LC's to one of the filters. The grooves will cause the first layer of molecules to align with the filter's orientation. At 90° angle to first piece you must then add a second piece of glass along with the polarizing film. Till the uppermost layer is at a 90° angle to the bottom, each successive layers of TN molecules will keep on twisting. The first filter will naturally be polarized as the light strikes it at the beginning. Thus, the light passes through each layer and is guided on to the next with the help of molecules. When this happens, the molecules tend to change the plane of vibration of the light to match their own angle. When the light reaches the far side of the LC substance, it vibrates at the same angle of the final layer molecules. The light is only allowed an entrance if the second polarized glass filter is same as the final layer.

Difference between LCD TV and LED TV

① LED TVs are technically a subset of LCD TV since the basic technology principle is same but backlighting is different.

② LCD TVs use fluorescent lights for backlighting whereas LED TVs use light emitting diodes.

③ The placements of light in LED TV can vary, but in LCD TV, they are always behind the screen. The Light Emitting Diode in LED TV can be placed either behind screen or around its edges.

④ ~~The diff~~ LED TVs are generally thinner than LCD TVs

⑤ LED TVs are more energy efficient than LCD TVs as they consume 20-30% energy lesser for same screen size

⑥ LED TVs glow on exposure to electric current. LCD TVs glow when the mercury vapours in the lamps create UV rays which in turn cause the phosphor coating of lamps to glow.

Ans 5

Charge Coupled Device (CCD)

CCDs are used for high resolution imaging. They are particularly useful in astronomy, where scientists have taken advantage of extreme sensitivity to light.

This aspect of the device has many practical applications, including laboratory research where detection of low light levels is needed.

Images taken by a CCD need to be corrected for certain factors, including dark noise, readout noise, and saturation among others.

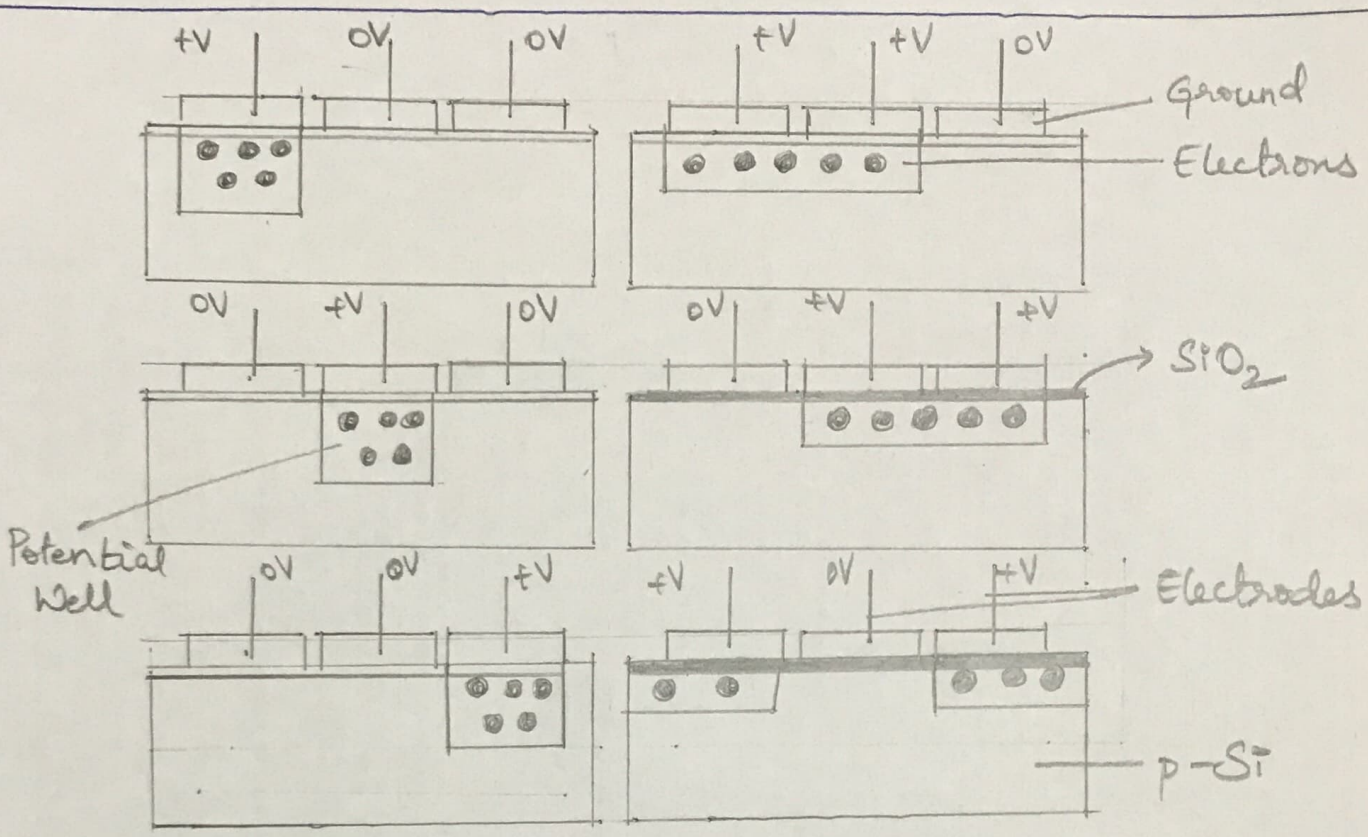
It is made of a 2D array of Metal-Oxide-Semiconductor capacitors, each capacitor represents a pixel. Each pixel acts like a bucket ~~like~~ of electrons

Working Principle

In a CCD for capturing images, there is a photoactive region (an epitaxial layer of silicon) and a transmission region made of a shift register (the CCD only).

An image is projected through a lens onto the capacitor array (the photoactive region), causing each capacitor

to accumulate an electric charge proportional to the light intensity at that location. A 1D array, used in line-scan cameras, captures a single slice of the image, whereas a 2D array, used in video and still cameras, captures a 2D picture corresponding to the scene projected onto the focal plane of sensor. Once the array has been exposed to the image, a control circuit causes each capacitor to transfer its contents to its neighbour (operating as a shift register). The last capacitor in the array dumps its charge into a charge capacitor amplifier, which converts the charge to voltage. By repeating this process, the entire circuit contents of the array in the semiconductor is converted by the controlling circuit to a sequence of voltages. In a digital device, these voltages are then sampled, digitized and usually stored in memory; in an analog device (such as an analog video camera), they are processed into a continuous analog signal (e.g., by feeding the output of the charge amplifier into a low-pass filter), which is then processed and fed out to other circuits for transmission, recording or other processing.



Thermographic Camera / Thermal Imager

It is also called IR camera or thermal imaging camera. It is a device that ~~is used to~~ creates images using IR radiation. They are sensitive to wavelengths 1μm to 14μm.

Practice of capturing & analyzing data such camera provides is called thermography.

Working Principle

① All objects emit a certain amount of black body radiation as a function of their temp.

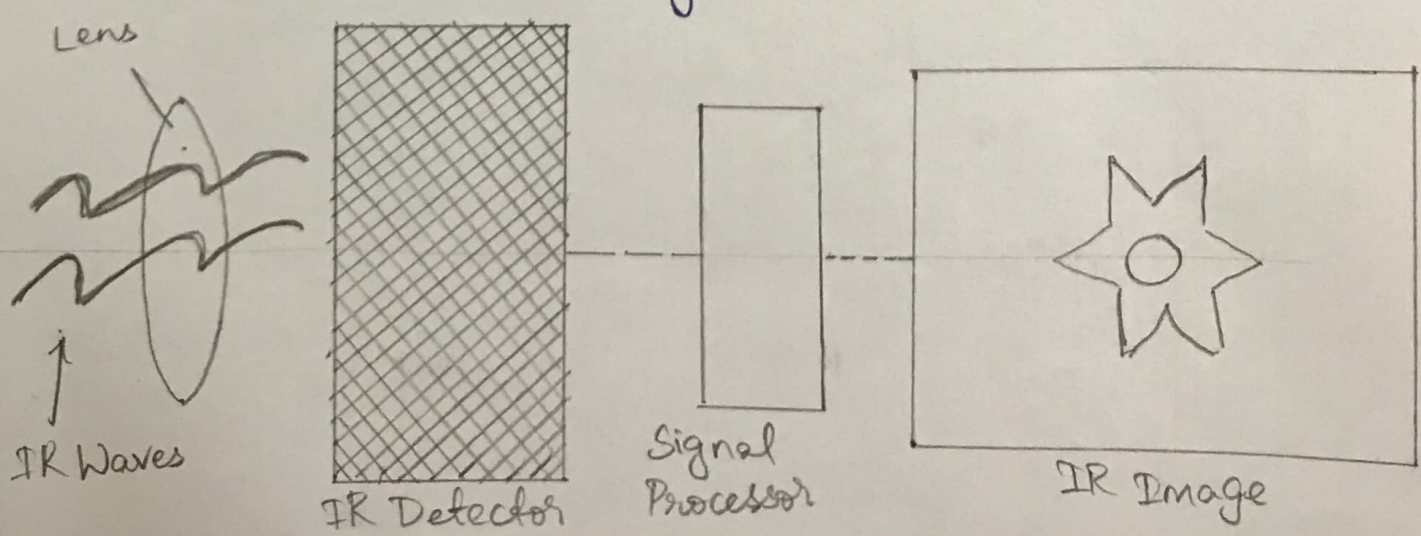
② Generally speaking the higher an object's temperature, the more IR radiation is emitted as black body radiation. It works in even total darkness because ambient light level doesnot matter.

③ A major difference with optical cameras is that focusing lenses can't be made of glass, as glass blocks long-wave IR light. Typically, spectral range of thermal radiation is from 7-14 μm.

④ Special materials such as Germanium, Calcium Fluoride, Crystalline Silicon or newly developed special type of chalcogenide glasses must be used.

⑤ Except for Calcium Fluoride, all these materials are quite hard & have high Refractive Index (Ge, n=4) which leads to very high Fresnel reflection from uncoated surfaces (up to more than 30%).

⑥ For this reason most of the lenses for thermal cameras have antireflective coatings. Higher cost of these special lenses is one reason why thermographic cameras are more costly.



Differences between CCD and Thermal Image

	CCD	Thermal Image
1	It is used in digital photography, astronomy	Used in thermography, fire-fighting, astronomy research telescopes.
2	It is made of array(2D) of MOS capacitors	Made of Ge, CaF_2, crystalline Si or chalcogenide glasses.
3	Acquires image as electric charge	Uses Blackbody radiation to capture image.
4	Converts input to electronic signal which is processed by software/equipment to produce image.	Creates image using IR radiation.
5	Generates high resolution images	Generates low resolution images.
6	Sensitive to wavelength of 1μm or shorter	Sensitive to thermal radiation from 1μm – 14μm

Ans 6

Polarization Microscope

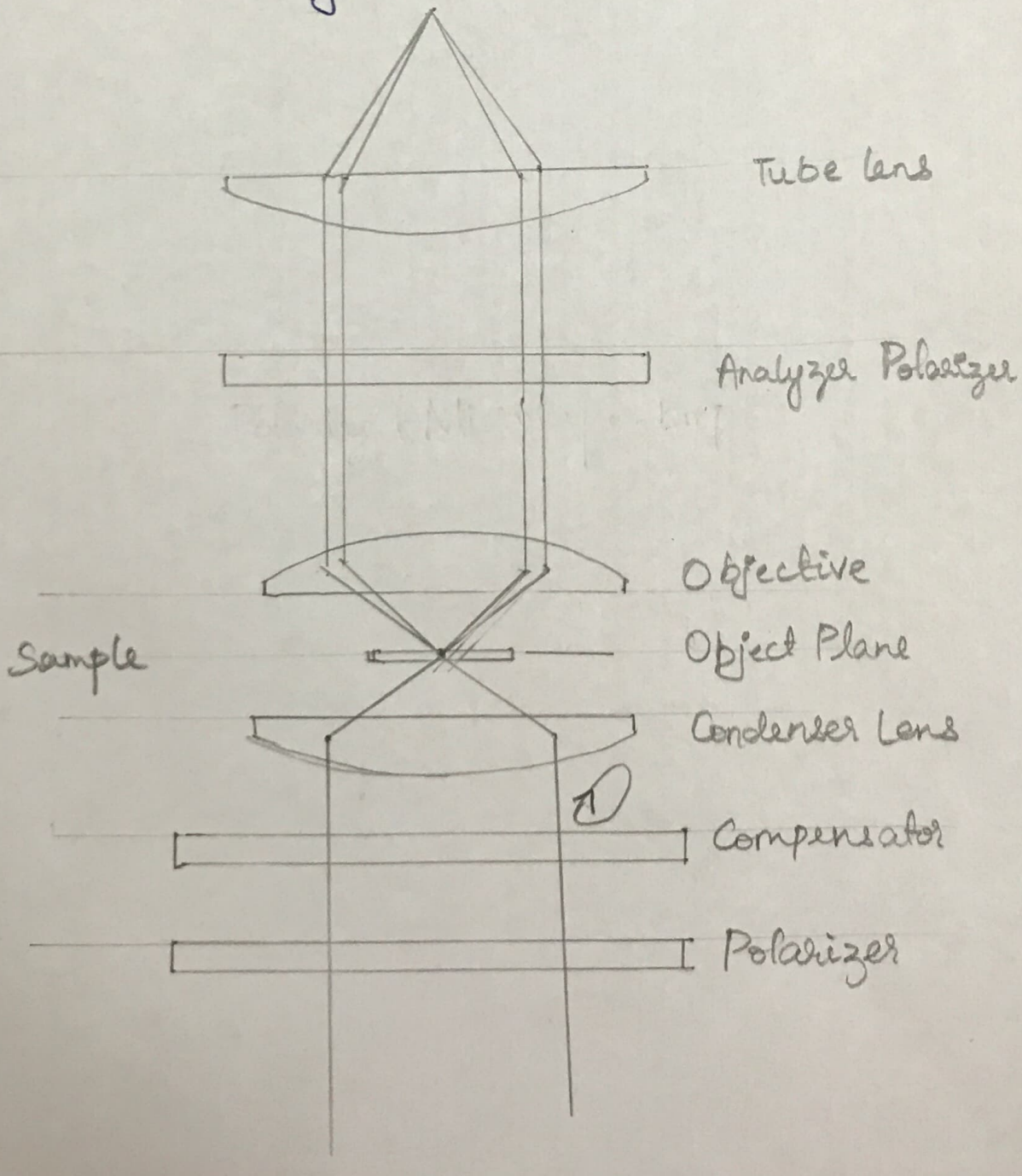
Polarized light microscopes work by converting unpolarized light to polarized light. This is achieved by adsorption of light vibrational movement in one specific direction. This can be done by certain natural minerals, including tourmaline or by synthetic films that perform same function.

Polaroid filters consist of tiny crystallites of iodoquinine sulphate which are oriented in same direction and embedded in a polymeric filter. This prevents migration and change in orientation of crystals. The device which selects plane-polarized ~~from~~ light from natural or unpolarized light is called a polarizer.

In the microscope, a polarizer intervenes between light source and sample. Thus, the polarized light source is converted into plane polarized light before it hits the sample. This polarized light falls on doubly refracting

specimen which generates two wave components that are at right angles to each other. These 2 waves are called ordinary and extraordinary rays.

The waves pass through the specimen in different phases. They are combined using constructive & destructive interference by an analyzer. This leads to final generation of a high-contrast image.



Digital Holographic Microscope (DHM)

Holography was invented by Dennis Gabor and has a profound use in light microscopy.

Basic concept of DHM is to magnify hologram image by adopting an optical lens system so that microscope fringes can be resolved.

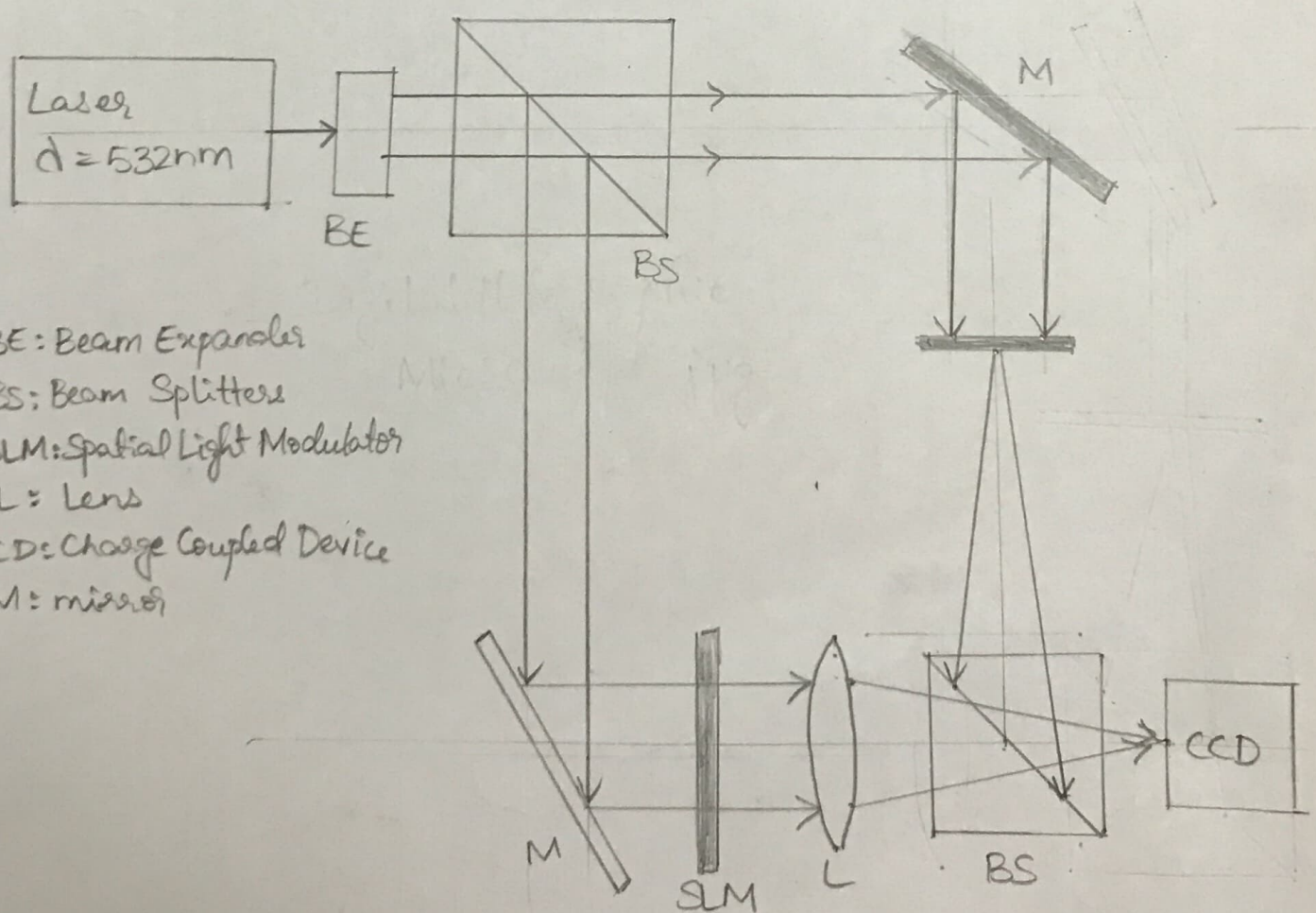
DHM, unlike other microscopy, doesn't record projected image of object, rather light wavefront information originating from object is digitally recorded as a hologram.

Imaging lens in traditional microscopy is replaced by computer algorithm.

To create the hologram, the illumination needs to be a coherent light source, like a laser. The laser light is split into an object beam and a reference beam. The expanded object beam illuminates the sample to create the object wavefront. After the object wavefront is collected by a microscope objective, the object and reference wavefronts are joined by a beam splitter to

interfere and create the hologram. Using the digitally recorded hologram, a computer acts as a digital lens and calculates a viewable image of the object wavefront by using a numerical reconstruction algorithm.

Commonly, a microscope objective is used to collect the object wavefront. However, as the microscope objective is only used to collect light and not to form an image, it may be replaced by a simple lens. If a slightly lower optical-resolution is acceptable, the microscope objective may be entirely removed.



BE: Beam Expander
BS: Beam Splitter
SLM: Spatial Light Modulator
L: Lens
CCD: Charge Coupled Device
M: mirror

Ans 7 I would define Engineering Optics as a field of study which emphasizes the application of the knowledge of Optics in designing instruments such as lenses, microscopes, telescopes, and any other devices that work on the principle of Optics. It basically deals with finding solutions to engineering problems and hence deals with the engineering aspects of optics.

Devices/Instruments where Engineering aspect is associated with Optics

1. Incandescent and Fluorescent Light Bulbs
2. Magnification Devices (Microscopes, Telescopes, Binoculars)
3. Flat-Panel Displays based on LCD, LED, Plasma
4. Optical Storage Devices like CD, DVD, Blu-ray Disc.
5. Photodiodes
6. Thermal Imagers
7. CCTV Cameras
8. Laser Printers
9. Optical Fibres.
10. Laser Speed Gun.

Before taking this course, I had done PH201 last semester, which I enjoyed thoroughly. I ~~had~~ thought PH301 would also be the same and now I know, it did.

I have gained good knowledge about various engineering applications of Optics. Looking back at this course, I am happy that I learnt about various sources of light, the use of optical detectors like Photodiodes, Charge Coupled Devices and Thermal Detectors.

I have gained a deeper insight about instruments like telescopes, microscopes. I read about these instruments in PH201 already but now I have also come to know more about the variants in each of them.

I got introduced to Optical Cryptography where learning about Polarization based Interferometers. I never imagined that images could be encrypted through optical means like those explained in class.

I have learnt about some of the display techniques currently in the market like LCD, LED, Plasma. These are some optics applications that I come ~~across~~ across daily in the form of TV, Computer and Mobile Phone Displays. and I am glad that I know how these things work.

During PH201, I got introduced to digital storage devices like CD, DVD, Blu-Ray disc. Now, in PH301 that was taught in depth. As a CS student, I am happy that I know QR codes

are, how they are made and how they work. I mean I got an essence of it.

Suggestions:

Sir, I really appreciate your effort in making the subject content clear to the students, not just through lectures but also through assignments. I wish we were in college to do some experiments in lab which would help understand theory. I thoroughly enjoyed the course, I gained a lot of knowledge from the course as mentioned before and I don't think there is anything to suggest about the course content. I am glad that I did such an informative course sir.

——X——X——